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AN INTRODUCTION TO NATURAL PHILOSOPHY.

VOL. II.

AN INTRODUCTION TO NATURAL PHILOSOPHY,

ILLUSTRATED WITH COPPER PLATES.

By WILLIAM NICHOLSON,

Non enim me cuiquam mancipavi, nullius nomen fero: multum magnorum virorum judicio credo, aliquid et meo vindico. Nam illi quoque, non inventa, sed quaerenda, nobis reliquerunt. SENECA.

IN TWO VOLUMES.

VOL. II.

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BOOK II.

SECT. III.

Of Fluids.

WHEN we reflect on the ſtructure of the univerſe, we may obſerve, not only that the world and its inhabitants are mutually formed for each other; but likewiſe, that thoſe actions which moſt conſtantly accompany the changes in bodies, are ſelected as the means by which intelligence from without is received by the ſenſes. The motion of light is choſen to give us notice of the exiſtence of bodies which are not immediately acceſſible, and the motion of the fluid air, by which we are ſurrounded, is made the object of a ſenſe whoſe advantages are too obvious to need enumeration,

namely, the hearing. The firſt has already been ſpoken of, and regularity directs our attention to the ſecond: for which purpoſe we ſhall firſt take a curſory view of the general properties of fluids, and next proceed to illuſtrate thoſe of the air.

CHAP. I.

Of Hydroſtatics; or the Effects which ariſe from the Gravity of Fluids.

A FLUID is a body whoſe parts readily yield to any impreſſion, and in yielding, are eaſily moved amongſt each other.

The cauſe of fluidity is not perfectly known. Some are of opinion that the particles of fluids are ſpherical, and, in conſequence of their touching each other in few points, cohere very ſlightly, and eaſily ſlip or ſlide over each other. But that the particles of fluids are of the ſame nature or figure as thoſe of ſolids, appears from the very frequent converſion of the one into

into the other. It does not ſeem rational to ſuppoſe that the particles of gold, lead, glaſs, &c. when in fuſion, are rendered ſpherical by the action of the fire, and when that action ceaſes, that the particles reſume their former, perhaps cubical, figure, as the bodies become ſolid by cooling. Neither can we imagine, with any degree of probability, that the particles of water are changed by cold, when it becomes a ſolid and brittle lump of ice, and are again reinſtated in their original form, when the ice, by diſſolution, is again turned to water.

The cauſe of fluidity, then, does not appear to depend on the figure of the particles, but probably on their ſmallneſs and want of coheſion.

If the particles of a body cohere ſtrongly together, it is evident that they will not eaſily move amongſt each other. An imperfect coheſion muſt therefore be one of the properties of a fluid maſs; and that the ſmallneſs of the particles is requiſite to fluidity will appear by conſidering, that the ſurface of a body compoſed of ſmall particles muſt be much

more ſmooth and even than the ſurface of a body compoſed of larger particles: that two flat bodies may be conceived to conſiſt of particles ſo ſmall, that their ſurfaces ſhall differ inſenſibly from perfect planes: that theſe bodies, if placed on each other, will ſlide without the leaſt ſenſible friction: and that if the particles of theſe bodies thus placed on each other be, by any means, deprived of the whole or the greateſt part of their coheſion, the bodies will not only ſlide on each other in the juſt mentioned plane, but the parts of the maſs will alſo ſlide on each other in any other direction whatſoever. Conſequently they will readily yield to any impreſſion, and in yielding, be eaſily moved amongſt each other. That is, they will conſtitute a fluid maſs.

If the particles of a body be without coheſion, they yield to an impreſſed force; but if, at the ſame time, they be not ſufficiently minute, the maſs is deprived of the ſecond circumſtance of the definition; for the parts do not eaſily move amongſt each other. Such are powders; which nevertheleſs,

leſs, yield more readily, the ſmaller the particles are of which they are compoſed.

It is not practicable to reduce a ſolid body to a fluid by pulverizing; for, however fine the powder may be, the coheſion of its parts prevents their eaſily moving among each other. But, if this coheſion be diminiſhed by heat or otherwiſe, pulverized bodies may reſemble fluids. Thus, fine powder of alabaſter, or plaiſter of Paris, heated over the fire in a flat diſh, will be agitated in great waves like a boiling fluid, and may be ſtirred with a ſtick or ladle, without affording the reſiſtance it did when cold. And a diſh of ſand placed on the head of a drum which is briſkly beaten, will, in almoſt every particular, imitate the properties of a fluid; heavy bodies will immediately ſink in it to the bottom, light bodies will emerge to the top, and if an hole be made in the ſide of the diſh, the ſand will ſpout forth like water.

That ſcience, which treats of the effects which ariſe from the weight of fluids, is called hydroſtatics.

The parts of fluids are heavy; but becauſe the upper parts reſt upon, and are ſuſtained by, the parts beneath, and becauſe, by the property of fluids, the parts are readily moved in all directions, upwards as well as downwards, they do not at firſt conſideration appear to be heavy.

The bottom of an upright priſmical or cylindrical veſſel is preſſed by the whole weight of the fluid contained; and as the weight of the fluid is in proportion to its height, ſo is likewiſe the preſſure. Thus in the cylinder AB (fig. 95.) when filled to C, the bottom is preſſed by, or ſuſtains a certain weight, ſuppoſe one pound; if it be filled to D, the preſſure becomes two pounds; if to A, three pounds, &c.

The whole of any fluid maſs may be imagined to conſiſt of a number of columns of an inconſiderable thickneſs, which ſtand perpendicularly on the baſe of the containing veſſel, and preſs the ſame with their reſpective weights. The preſſure, then, if the height remain the ſame, is as the number of columns, and this number is as the area of the baſe. Conſequently in veſſels whoſe baſes

differ

differ as to area, and which contain fluids of the ſame denſity, but different heights, the preſſure will be in the compound ratio of the baſes and heights; that is, as the area of the baſe multiplied by the height of the fluid in one veſſel, is to the area of the baſe multiplied by the height of the fluid in the other veſſel, ſo is the preſſure ſuſtained by the baſe of the one, to the preſſure ſuſtained by the baſe of the other veſſel.

In like ſituations, the preſſures of fluids will be as their denſities.

The denſities being diſcoverable only by the different weights of bodies of the ſame bulk, the comparative denſities of bodies are therefore called their ſpecific gravities.

If the columns of which a fluid maſs was ſuppoſed to conſiſt, were formed of particles lying in ſtrait perpendicular lines, the preſſure of the fluid would be exerted on the bottom of the veſſel only; but, as they are ſituated in every irregular poſition, there muſt, of conſequence, be a preſſure exerted in every direction; which preſſure muſt be equal at equal depths. For if any part of the whole maſs were not equally preſſed on all

ſides, it would move towards the ſide on which the preſſure was leaſt; and would not become quieſcent till ſuch equal preſſure was obtained. The quieſcence of the parts of fluids is therefore a proof that they are equally preſſed on all ſides.

On this account it is, that fluids, as far as they are not prevented by external accidents, do always conform their upper ſurface to the plane of the horizon. For if any column or part of the fluid be elevated above the reſt, its lateral preſſure will cauſe the elevated part to ſpread ſideways over the ſurface, till it becomes uniformly of the ſame height, or horizontal.

The equal preſſure of fluids in every direction, being underſtood, is uſed to account for many phenomena which happen to them in different circumſtances; ſome of which are the following.

The horizontal bottom of a veſſel is preſſed by, and ſuſtains no more nor leſs than the weight of a column of the fluid it contains, whoſe baſe is the bottom itſelf, and whoſe height is that of the fluid.

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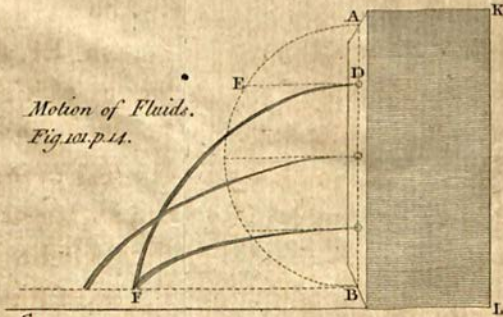
Preſsure of Fluids. Fig.98.p.9.

Preſsure of Fluids.
Fig.98.p.9.

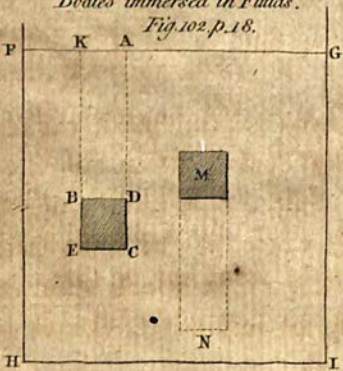
Hydrostatical Paradox.
Fig.99.p.10.

Hydrostatical Paradox Fig.100.p.11.

Motion of Fluids.
Fig.101.p.14.



Bodies immersed in Fluids.
Fig.102.p.18.



Areometer
or
Hydrometer.
Fig.103.p.25.

Areometer
or
Hydrometer.
Fig.104.p.27.

In the veſſel ECDF (fig. 96.) the bottom CD ſuſtains no more than the column ABDC. For the other parts of the contained fluid can only preſs the column ABDC laterally, and therefore contribute not at all to the increaſe of the weight or preſſure on the bottom CD; but reſt intirely on the ſides EC and FD.

Alſo in the veſſel ECDF, (fig. 97.) the bottom EF ſuſtains a preſſure equal to the weight of a column whoſe baſe is EF, and height equal to CA. For the preſſure at AB is equal to the weight of the column ABCD, and its lateral preſſure, which is equal to the ſame weight, muſt cauſe the parts between EA and BF to preſs the bottom with an equal force in proportion to the ſurfaces they cover. Conſequently, the effect will be the ſame as if the whole fluid were of the height CA.

From theſe two caſes combined, the reaſon is evident, why fluids contained in the ſeveral parts of veſſels, as A and B, (fig. 98.) remain every where at the ſame height. For the loweſt part at which they communicate, may be regarded as the common baſe;

baſe; and the fluids, which reſt thereon, are in equilibrio then only, when their heights are equal, however their quantities may vary.

The hydroſtatical paradox, as by ſome it is called, depends on the equal preſſure of the parts of fluids every where at the ſame depth. It is this.

Any quantity of fluid, however ſmall, may be made to counterpoiſe and ſuſtain any weight, how large ſoever.

Let ABDG (fig. 99.) repreſent a cylindrical veſſel, to the inſide of which is fitted the cover C, which, by means of leather at the edge, will eaſily ſlide up and down in the internal cavity, without permitting any water to paſs between its edges and the ſurface of the cylinder. In the cover is inſerted the ſmall tube CF, which is open at top, and communicates with the inſide of the cylinder beneath the cover at C. The cylinder is filled with water, and the cover put on. Then, if the cover be loaded with the weight, ſuppoſe of a pound, it will be depreſſed, the water will riſe in the tube to E, and the weight will be ſuſtained. If another pound be added, the water will riſe to F, and the weight

weight will be ſuſtained, and ſo forth, according to the weight added, and the length of the tube. Now, the weight of the water in the tube is but a few grains; yet its lateral preſſure ſerves to ſuſtain as much as the weight of a column of water, whoſe baſe is equal to that of the cylinder, and height equal to that in the tube. Thus, the column EC produces a preſſure in the water contained in the cylinder, equal to what would have been produced by the column AadD; and, as this preſſure is exerted every way equally, the cover will be preſſed upwards with a force equal to the weight of AadD: conſequently, if AadD would weigh a pound, EC will ſuſtain a pound. And the like of other heights and weights. And by diminiſhing the diameter of the tube, any quantity of water, how ſmall ſoever, will, in theory, ſuſtain any weight, however large.

The ſame may be ſhewn ſimpler, thus;

Let AGBD (fig. 100.) repreſent a hollow cylinder, and MN a cylinder of wood, which nearly fills its cavity. In the cylinder, ſuppoſe a little water, whoſe ſurface is gb; then, if the wooden cylinder be put into the hollow

one

one, the water will riſe between the ſurfaces to a and d, and the wood will be ſuſtained floating. The nearer the wooden cylinder approaches to the ſize of the cavity, the leſs water is neceſſary for the experiment.

CHAP II.

Of the Motion of Fluids which ariſes from the Preſſure of their ſuperincumbent Parts.

THE preſſure of fluids being ſhewn to be in proportion to their depths, it will be eaſy to find the celerities with which they ſpout forth from apertures in the bottoms or ſides of veſſels.

For the motion produced in the fluid muſt follow the ſame proportion as the preſſure. (Law. 2. p. 25. vol. i.) The quantity of this motion is the product of the quantity of the fluid emitted, multiplied by the velocity. Now, the quantity of the fluid emitted is as the velocity with which it ſpouts forth. If the velocity be double, a double quantity is emitted; if treble, a treble quantity. Whence it follows, that the quantity of mo-

tion (which in the one caſe is as the double velocity multiplied by the double quantity emitted; in the other caſe, as the treble velocity multiplied by the treble quantity, and the like for other degrees of velocity) is as the ſquare of the velocity. The motion being as the depth of the fluid, ſo muſt therefore be the ſquare of the velocity. The velocity itſelf then is as the ſquare-root of the depth.

The velocities of falling bodies are governed by the ſame ratio; for the ſquares of the times are as the ſpaces deſcribed, and the velocities are as the times. Whence the velocities are as the ſquare-roots of the ſpaces deſcribed by the falling bodies. And, ſince at the beginning of motion the velocity of a falling body is the ſame with that of the uppermoſt parts of a fluid, both endeavouring to deſcend by the mere force of gravity; it follows, that the velocity of the fluid which ſpouts forth at any aperture, beneath the ſurface of the fluid contained in any veſſel, is equal to the velocity which a body would acquire by falling through a ſpace equal to the

diſtance

diſtance between the aperture and the ſurface.

And this velocity is ſuch as in an equal time would carry the body uniformly through a ſpace double to that which it had before deſcribed from the beginning of its motion. For the laſt velocity BC, (fig. 4.) with the time AB, will form a parallelogram equal to twice the triangle ABC.

Let AKLB (fig. 101.) repreſent a veſſel which is conſtantly kept full of water. On the perpendicular ſide AB deſcribe the ſemicircle AEB, and from any point D in the line AB draw the horizontal line DE, meeting the circle in E. Then, if an aperture be made in the veſſel at D, ſo that the water may ſpout forth in an horizontal direction, it will fall on the level plane LG, on which the veſſel is placed, at F, and the diſtance BF ſhall be twice the length of the line DE.

For AD is equal to half the horizontal ſpace the emitted fluid deſcribes in the time a body would fall from A to D; and the times of falling bodies are as the ſquare-roots of the ſpaces through which they paſs: therefore,

As

As the time, which is expreſſed by the ſquare root of AD,

Is to half the ſpace which the emitted water deſcribes in that time, to wit, the line AD,

So is the time the water employs in falling from D to B, which is expreſſed by the ſquare root of DB,

To half the ſpace deſcribed by the horizontal motion of the emitted water in that time, namely, the line DE,

Whence it * appears, that DE is a geometrical mean proportional between AD and DB: and that the readieſt method of calculating the diſtance is to multiply the height of the water above the orifice by the height of the orifice above the plain, and the ſquare-root of the product will be half the horizontal diſtance to which the water will ſpout. And

It may, perhaps, be a ſatisfaction to the Tyro to ſee an illuſtration of this.

Let $a = AD$, $d = DB$ and $x = DE$.

Then the above proportion is	$a^{\frac{1}{2}} : a :: d^{\frac{1}{2}} : x$
Which gives the equation	$a^{\frac{1}{2}}x = ad^{\frac{1}{2}}$
Square it	$ax^2 = a^2d$
Divide by a	$x^2 = ad$
Extract the ſquare-root	$x = \overline{ad}^{\frac{1}{2}}$

the line DE (by 13. e. 6.) will terminate in the circle's periphery. The diſtance therefore will be greateſt when the water iſſues from an aperture at the center C; and equal from apertures equally diſtant above or below the center, as from D and d.

Since the velocity of water, which is emitted from any veſſel, is equal to the velocity which a body would acquire by falling from the height of the ſurface to the aperture, it is plain, that if it ſpout forth in a direction perpendicularly upwards, it will proceed, with a motion uniformly retarded, to the height of the ſurface, and then fall again by its own weight. If it ſpout forth, in a direction obliquely upwards, its velocity being known, its motion muſt be compounded with the motion produced by the perpendicular action of gravity, by which it will be found to move in the curve of a parabola, as other projected bodies do, whoſe perpendicular height will vary according to the obliquity of the direction of the fluid.

On theſe conſiderations depends the performance of fountains; for the conſtruction of which there is provided a reſervoir, elevated conſiderably

conſiderably above the plane in which the fountain is to be made. A pipe, communicating with the reſervoir, is conveyed to the middle of a baſon, and by means of a perpendicular ſpout, called the adjutage, throws the water up in the air to a height which is in the level of the ſurface of the water in the reſervoir.

But in applying theſe obſervations to practice, there are many circumſtances that, like friction in mechanical engines, tend to diminiſh the quantities of motion. There are few fluids that have not a conſiderable degree of coheſion or tenacity, which prevents their parts from moving as freely as otherwiſe they would have done; and the friction againſt the ſides of tubes very much retards the motion of the included fluids, if the tubes be ſmall or crooked, and the velocity great. In fountains, eſpecially where the fluid is thrown perpendicularly upwards, the part which is falling reſts upon the column which aſcends, and prevents its arriving at the height to which its motion would have carried it; beſides which, the reſiſtance of the air, and other cauſes, join to the ſame

effect. We muſt not therefore expect in theſe organs, more than in any others, that the performance will equal the theory; yet, it is not difficult to make the proper allowances, ſo as to find their real effects by calculation; but our purpoſe, being general, does not extend to the variety of particulars which offer themſelves.

CHAP. III.

Of Specific Gravities.

IF a ſolid body be plunged in a fluid it will be preſſed on all ſides, but not equally. Let DBCE (fig. 102.) repreſent a ſolid body, immerſed in the fluid contained in the veſſel FGIH, then the ſides DE and BC will be equally preſſed; the upper ſurface DB will be preſſed with the weight of a column, whoſe baſe is DB, and height AB, and the under ſurface will be preſſed upwards with a force equal to the weight of a column AC. The body will therefore be impelled upwards with a force equal to the exceſs of AC above BC; that

is,

is, with a weight equal to that of a column of the fluid whoſe length is BC. Whence it appears, that every priſm, whoſe axis is perpendicular to the horizon, will, if it be immerſed in any fluid, be impelled upwards by a force which is equal to the weight of a quantity of the fluid of the ſame bulk with the priſm. And ſince any ſolid whatſoever may be conceived to be formed of an indefinite number of ſuch priſms, it is evident that the rule is true of all bodies, without reſpect to figure.

But as all bodies, by the force of gravity, tend downwards, it depends upon that gravity, whether the immerſed body ſhall aſcend or deſcend. If the weight of the body exceed that of an equal bulk of the fluid, it will deſcend; and on the contrary, if the weight of the body be leſs than that of an equal bulk of the fluid, the above-mentioned preſſure will prevail, and it will aſcend; if both be preciſely equal, the body will remain at reſt any where in the fluid.

Theſe things being conſidered, it appears that any body, how heavy ſoever, may be made to ſwim, or any body, how light ſoever,

to ſink, if means be uſed to keep off the preſſure of the fluid on the one or other ſide, as circumſtances require: for, if ABDK be ſuppoſed to repreſent an open tube, inſtead of a column of the fluid, and the body DBOE be applied cloſe to its lower orifice, ſo that the fluid may not enter the tube, the preſſure on DB will be taken off, and conſequently the body will be preſſed upwards with a force equal to the whole column AC. If that column be of ſufficient length, that is, if the body be immerſed ſufficiently deep, the preſſure will exceed the gravity of the body, and therefore ſuſtain it. In like manner, if M be a body applied to the open end of a tube, which is cloſed at N, the inferior preſſure being taken off, the body will ſink by means of the preſſure on the ſuperior ſurface.

Since the preſſure by which bodies immerſed in fluids are impelled upwards is in proportion to their bulks, it is plain that bodies of equal bulks will loſe the ſame quantity of abſolute weight when immerſed in fluids of equal denſity. Whence we have an exact method of determining the bulks of bodies

whoſe

whoſe weights are known, and from thence finding their ſpecific gravities. For their bulks being as the weights they loſe in the fluid, it follows,

As the bulk of one body (or the weight it loſes by immerſion)

Is to its maſs of matter, (or abſolute weight)

So is the bulk of any other body, (or the weight it loſes by immerſion)

To the maſs of matter (or abſolute weight) it would have, if of the ſame ſpecific gravity with the firſt body. Which weight laſt found being compared with the real weight of the latter body, ſhews the proportion of their ſpecific gravities.

For example; if 34 oz. of lead be weighed in water, and the diminution be 3 oz. and 15 oz. of tin be alſo weighed in water, and the diminution appear 2 oz. it is required to determine the proportion of their ſpecific gravities. For which purpoſe,

As the diminution in the lead 3, is to its weight 34, ſo is the diminution in the tin 2, to the weight of a maſs of lead of the ſame bulk $22\frac{2}{3}$ oz. which is to 15 as the ſpecific

gravity of lead is to that of tin, that is to say, in lower terms, nearly as $11\frac{1}{2}$ to $7\frac{1}{2}$.

But it is more usual and convenient to make rain-water the standard, and refer the other substances to it: thus, in the instances just mentioned, the weight of a mass of water equal in bulk to the lead is 3 oz. lead is therefore to water as 34 to 3, or as $11\frac{1}{2}$ to 1, and in like manner, tin is to water as 15 to 2, or as $7\frac{1}{2}$ to 1.

When the solid is lighter than the fluid in which it is weighed, an additional body of greater density may be joined to it; for instance, suppose a piece of cedar-wood, weighing 92 dwts. were required to be weighed; join to it, by means of a small hair or thread, a piece of lead, whose weight in water is known, and weigh them immersed together. The lead will then appear to weigh less by 58 dwts. than it did without the addition of the cedar; from whence it is evident, that the cedar is impelled upwards by a force that exceeds its own weight by that quantity, or, in other words, that a quantity of water, equal in bulk to the cedar, will weigh 92+58, or

150 dwts. conſequently the ſpecific gravities of water and cedar are in proportion as 150 to 94, or in lower terms, as 1 to $\frac{6}{10}$ nearly.

If the adjuſtment in this experiment be not quickly made, the water imbibed by the wood will render it ſpecifically heavier than before. In fact, wood is not ſpecifically lighter than water, but by means of the air-veſſels which run through its ſubſtance.

The beſt method to diſcover the ſpecific gravities of fluids is, to weigh the ſame ſubſtance in different fluids; and becauſe the diminution it ſuffers in weight is equal to the weight of a quantity of the fluid which is of the ſame bulk, we thence obtain the weights of equal quantities of different fluids, and the ſpecific gravities are as thoſe weights; thus, if a piece of glaſs weighed in oil of vitriol, loſe 42½ dwts. and when weighed in water only 25 dwts. their ſpecific gravities will be as thoſe numbers, or in lower terms, as 1 $\frac{7}{10}$ to 1.

In all theſe experiments, very nice ſcales muſt be uſed, and the body to be immerſed muſt be ſuſpended from one of the ſcales, by a

hoſe hanging by one thread, whoſe weight is inconſiderable. This branch of phyſiology is replete with many uſeful and entertaining experiments, by means of which the foregoing concluſions may be found in different manners. The following, though not quite ſo exact in practice as thoſe already mentioned, deſerves to be noticed, on account of its convenience and ſimplicity.

When a body floats at the ſurface of a fluid, the quantity of the fluid, which is diſplaced by the part immerſed, is equal in weight to the floating body. For ſince the body preſſes downwards with its whole weight, it muſt ſink till the preſſure, which the fluid exerts upwards, is equal to that weight. In this ſituation, ſuppoſe the fluid to be congealed, and the ſolid then removed: a cavity will be left in the fluid correſponding in form and magnitude with the immerſed part of the ſolid. Let this cavity be filled with a quantity of the ſame fluid, ſo that its ſurface may be level with the reſt, and the whole fluid then thawed. The fluid which occupies the place

of

of the ſolid will then be preſſed upwards with a force equal to that ſuſtained before by the ſolid, namely, equal to the weight of the ſolid. But it is not moved by that force, for the ſurface continues level, as before the thaw. The laſt mentioned quantity of fluid muſt therefore preſs downwards with an equal force. That is to ſay, the weight of a quantity of fluid equal in bulk to the immerſed part of a ſolid which floats on its ſurface, is equal to the whole weight of the ſolid.

By the ſame argument, it follows, that if a floating body be loaded with weights, ſo as to cauſe it to ſink deeper in the fluid, the additional parts immerſed will in bulk be equal to, or diſplace, parts of the fluid, whoſe weights are equal to thoſe with which the floating body was loaded.

By theſe principles is conſtructed the areometer or hydrometer, which is as follows. AB (fig. 103.) is a tube of glaſs which is joined to a hollow ball C, at the bottom of which is a ſmaller ball D. In the cavity D is placed a quantity of quickſilver, by which

the

the inſtrument is ſo poiſed, that it ſwims in proof ſpirits or wine immerſed to the point M. Therefore a quantity of proof ſpirits equal in weight to the whole inſtrument, will be equal in bulk to the immerſed part. If it be immerſed in another liquid whoſe ſpecific gravity is greater, it will ſwim with the tube higher out of the water, ſuppoſe to the point B. Then the weights of the quantities diſplaced remaining the ſame, their bulks will be as the immerſed points of the hydrometer, and the ſpecific gravities of the fluids will be inverſely as thoſe bulks. The proportion which any length of the tube bears to the whole bulk of the inſtrument being known, it will not be difficult to graduate the tube ſo as to indicate the ſpecific gravities by inſpection.

But this inſtrument is very confined in its uſe; for if the liquors differ conſiderably in ſpecific gravity, they will exceed the limits of the graduation: thus the hydrometer which is adapted for ſpirits, will ſwim in water with part of the ball above the ſurface; and if it be adapted to water, it will not ſwim in

ſpirits

ſpirits at all. It is true this may be remedied, either by lengthening or widening the tube: but the firſt is inconvenient, and the latter would make the graduations ſo ſhort, as to render them of no uſe.

To make this inſtrument of more ſervice, there has been added a little plate or diſh DD (fig. 104.) at the top of the tube, upon which may be placed weights, as convenience requires. For example, if the whole inſtrument float immerged in ſpirits to the point M, it will require an additional weight to ſink it to the ſame depth in water. Suppoſe the inſtrument to weigh 10 dwts. and to be adjuſted to rectified ſpirits of wine, it will then require the addition 1 $\frac{6}{10}$ dwt. to ſink it to the ſame point in water. Conſequently it appears, that the ſpecific gravity of water is to that of ſpirits of wine, as 11 $\frac{6}{10}$ to 10, or in lower terms, as 1 to $\frac{86}{100}$.

This is the beſt hydrometer, both in reſpect to exactneſs and facility in practice. That which is uſed by the officers of Exciſe, is very well adapted for its purpoſe, which is more confined; it differs from that here deſcribed,

described, by having its additional weights ſcrewed on at a ſtem at E. It is moſt convenient that theſe inſtruments ſhould be made of copper.

Here follows a liſt of the ſpecific gravities of bodies, extracted from the writings of the beſt modern philoſophers,

Table of Specific Gravities.

Metals.	
Refined Gold	19640.
English Guinea	18888.
Quickſilver	14619.
Lead	11344.
Refined Silver	11091.
Copper from Japan	9000.
Copper from Sweden	8843.
Hammered Braſs	8349.
Caſt Braſs	8100.
Elaſtic Steel	7820.
Soft Steel	7738.
Iron	7645.
Pure Tin	7471.

Transparent Bodies.	
Diamond	3400.
Glaſs of Antimony	5280.
Pſeudo-Topazius	4270.
Cryſtal Glaſs	3150.
Green or common glaſs	2620.
Rock Cryſtal	2650.
Iſland Cryſtal	2720.
Selenitis	2252.
Amber	1040.
Rain Water	1000.
Rectified Spirits of Wine	866.
Etherial Spirits of Wine	732.
Air	1 ¼.

Miscellaneous.	
Biſmuth	9700.
Cinnabar natural	7300.
Cinnabar factitious	8200.
Lapis Calaminaris	5000.
Hematites	4360.
Turbith Mineral	8235.
Bohemian Grenate	4360.
Jaſper	2666.
Sulphur	1800.
Human Blood	1040.
Marble	2704.
Nitre	1900.
Wax	995.

CHAP. IV.

Of the Reſiſtance which Fluids make to Bodies moving in them.

WE muſt not conclude the general account of fluids, without explaining the reſiſtance they make to the motions of bodies immerſed in them. The phenomena which this reſiſtance produces are continually offering themſelves to our notice, and appear in every motion that paſſes under our obſervation.

When a body is immerſed in a maſs or quantity of fluid matter, and is in motion, it muſt ſeparate the parts of the fluid from each other as it moves. If the parts of the fluid be without coheſion or tenacity, this ſeparation will be attended with no difficulty; but if the tenacity be conſiderable, it will require a conſiderable force to overcome it. A part of the motion muſt therefore be loſt in producing this effect. And, in the ſame

fluid, the more parts are divided in a given time, the greater quantity of the motion muſt be loſt or employed for that purpoſe. But a body, moving through an uniform fluid, divides a greater or leſs number of its parts, in proportion as the velocity of its motion is greater or leſs. Conſequently, the reſiſtance which an uniform fluid makes, by reaſon of its tenacity, to a body immerſed and moving in it, is in proportion to the velocity of the moving body.

But there is another reſiſtance of greater conſequence, which fluids make to bodies immerſed and moving in them, and which ariſes from the inertia of their parts. Thus, if a body of a given magnitude be moved in a fluid, it muſt give motion to a certain quantity of that fluid, and the reaction of that quantity will deſtroy part of the motion of the body. Now a body moving through an uniform fluid, gives motion to a greater or leſs number of its parts, in proportion to the velocity of its motion, and is therefore reſiſted in the ſimple proportion of the velocity on that account. Again, a body moving through an uniform fluid, communicates a greater or

leſs

leſs quantity of motion to each of its parts, in proportion to the velocity of its motion, and is therefore reſiſted in the ſimple proportion of the velocity on that account. On both accounts, then, the reſiſtance which ariſes from the inertia of the fluid, is in the duplicate proportion of the velocity of the moving body.

When the ſame body is ſpoken of, the reſiſtance and retardation follow the ſame ratio; but, in different bodies, they differ in the ſame manner as motion and velocity. Reſiſtance ſignifies the quantity of motion, and retardation the quantity of velocity, which is deſtroyed: for example, if a body move with a given velocity in a fluid, and loſe half its motion by the reſiſtance, its retardation will be half its velocity: but if another body of the ſame bulk, but twice its weight or maſs of matter, move with a like velocity in the ſame fluid, it will be equally reſiſted; but, having twice the quantity of motion, will only loſe one-fourth of its velocity. Thus, though the reſiſtances be equal, the retardation in the latter inſtance is only half the quantity of that in the former.

In

In fluids which are not glutinous, the reſiſtance, ariſing from their tenacity is inconſiderable, eſpecially in ſwift motion: in which caſe, the reſiſtance from the inertia increaſing as the ſquares of the velocities, while that from the tenacity increaſes only as the velocities themſelves, the proportion of the latter to the former, becomes ſo ſmall that it may be neglected. It is uſual, therefore, to neglect that reſiſtance which ariſes from the tenacity of fluids.

In like circumſtances, the reſiſtances of fluids are as their denſities. For the quantity of matter to be moved is in that proportion.

If a cylinder be moved through an uniform fluid in the direction of its axis, it will ſuffer a reſiſtance equal to that of a ſphere, whoſe diameter and velocity of motion in the ſame fluid are equal to thoſe of the cylinder. For proof of which, ſuppoſe the cylinder to be quieſcent in the middle of a priſmical canal or tube, its axis coinciding with that of the tube. Let this tube be filled with the fluid, and conceive the fluid to be moved through it with a given velocity. Then the

fluid will paſs between the ſides of the tube and the cylinder, and its motion will be impeded by its being reduced to paſs through a narrower ſpace. If the ſphere be ſubſtituted in the place of the cylinder, the ſpace through which the fluid is reduced to paſs will be preciſely the ſame, and conſequently its motion will be equally impeded. And, becauſe action and reaction are equal, the cylinder and ſphere in theſe circumſtances will be equally acted upon by the fluid. Now, let the fluid be ſuppoſed quieſcent, and the cylinder or ſphere moved with the ſame velocity, and in the contrary direction to that in which the fluid was before moved; and the relative motions of the fluid and immerſed body will be the ſame as before. Conſequently the cylinder and ſphere, if moved with equal velocities through a priſmical veſſel containing a fluid, will be equally acted upon in the contrary direction to their motions; that is, they will be equally reſiſted.

In like manner, it is ſhewn, that all bodies whoſe * orthographic projections taken by rays in the direction of their motions, are

* The ſhadow of a body which is made by the inter-

equal,

equal, will be equally reſiſted when moving in a priſmical veſſel which is filled with a given fluid. For they equally impede the paſſing or relative motion of the fluid. And, ſince this equality of reſiſtance does not at all depend on the magnitude of the priſmical veſſel, the doctrine may be applied to bodies moving in an indefinitely extended fluid, or fluid contained in an indefinitely large priſmical veſſel. It may, therefore, be applied to all bodies in motion which are deeply immerſed in any fluid.

By a proceſs, which is too long to be inſerted here, it is demonſtrated *, that the reſiſtance which a fluid makes to a cylinder moving in it in the direction of its axis, is equal to the weight of a column of the fluid, whoſe baſe is equal to that of the cylinder, and height is equal to half the ſpace through which a body ought to fall in vacuo to acquire the velocity with which the cylinder moves.

Hence the reſiſtance and retardation of a body moving in any fluid may be found, if

ception of parallel rays, and which falls on a plane ſurface ſituate at right angles to the direction of the rays, is the orthographic projection of the outline of that body.

* Princip. 37. l. 2.

the velocity of its motion, its bulk and weight, together with the denſity of the fluid be known. An inſtance will render this familiar.

Suppoſe a globe of lead of three inches diameter, and 84 oz. troy weight to be moved in water, with a velocity of 2 feet in a ſecond; it is required to find the reſiſtance and retardation which the water makes to its motion?

A falling body, as has already been obſerved, deſcribes the ſpace of $15\frac{1}{12}$ Paris feet in a ſecond of time; which is equal to $16\frac{1}{10}$ Engliſh feet. But for the ſake of round numbers, let us call it 16 feet. And the laſt velocity of an equably accelerated motion, is ſuch as would, uniformly in the ſame time, deſcribe twice the ſpace already deſcribed *ab initio*. Now, the ſpaces deſcribed are as the ſquares of the velocities; therefore,

As the ſquare of the velocity of 32 feet per ſecond,	1024
Is to the ſpace by falling which that velocity was acquired,	16
So is the ſquare of 2, the given velocity,	4

To

To the ſpace by falling which it would be acquired - - - $\frac{6}{10}\frac{4}{14}$ or $\frac{1}{16}$.

The half of which, or $\frac{1}{32}$ of a foot, is the length of the column of water; and its diameter being three inches, it will weigh 2 $\frac{1}{2}$ oz. troy, which therefore ſhews the quantity of the reſiſtance.

The reſiſtance being thus diſcovered, we may conſider the effect in the ſame manner as if a body of 84 oz. had ſtruck with a velocity 2 againſt a quieſcent body of 2 $\frac{1}{2}$ oz. and eaſily diſcover the velocity of the body 84 after the ſtroke, and conſequently find its retardation.

For the motion of the firſt body before the ſtroke is expreſſed by 84 multiplied by 2, or 168; and the whole ſum of the motion is not altered by the mutual action of the bodies. Therefore, after the ſtroke, the quantity of motion continues to be 168, though the maſs is increaſed by the addition of 2 $\frac{1}{2}$, by that means becoming 86 $\frac{1}{2}$ inſtead of 84. To find the velocity, divide the quantity of motion, 168, by the maſs, 86 $\frac{1}{2}$, which gives 1 $\frac{9}{16}$, the difference between which and the former velocity 2 is the retardation, that is to ſay, $\frac{1}{16}$.

Thus it appears, that in order to maintain the uniform motion of a body in a fluid, a conſtant acceſſion of force is required to overcome the reſiſtance; but as, in general, there is no ſuch acceſſion in the motions which are performed about us, they all decay by degrees, and at length terminate.

It likewiſe appears, that when a body moves in any fluid, and is acted upon by any conſtant force, it can obtain but a certain degree of velocity. For, as the reſiſtance increaſes with the velocity, but in a higher proportion, namely, as the ſquares, it is plain that the reſiſtance at a certain period of the acceleration, will become equal to the conſtantly acting force; after which the body will proceed uniformly, and the conſtantly acting force will be employed in overcoming the reſiſtance. On this account it is, that bodies which ſink in water, or other fluids, by the force of gravity, do ſoon acquire their utmoſt velocity, and afterwards proceed uniformly. And, in like manner, a ſhip, when it firſt gets under way, proceeds with an accelerated velocity, till the reſiſtance of the water becomes in equilibrio with the action of the wind

wind on its ſails, after which it proceeds uniformly, the force of the wind being entirely employed in overcoming that reſiſtance.

In mathematical ſtrictneſs it is not true, that a body in theſe circumſtances ever arrives at uniformity of motion; for the approach of the reſiſtance to an equality with the impelling force is repreſented by a converging ſeries, the number of whoſe terms is infinite: but the latter terms ſoon become too ſmall to be of any phyſical conſequence.

What is here ſaid of reſiſtances is to be underſtood of bodies deeply immerſed in fluids, the parts of which are compreſſed together, and non-elaſtic or incapable of condenſation. Friction is likewiſe neglected. Bodies which move at or near the ſurfaces of fluids, more eſpecially if they be obtuſe, cauſe the fluid to riſe into a heap before the body, at the ſame time that it ſubſides at the hinder part. In like manner, obtuſe bodies, moving in elaſtic fluids, condenſe that part of the fluid towards which they are moving, while the part from which they recede is rarefied. In theſe caſes the reſiſtances are greater than appears by the principles juſt treated of.

BOOK II.

SECT. IV.

Of the Air.

CHAP. I.

Of the general Properties of the Air; and of the Dimenſions of the Atmoſphere.

CONTINUAL experience evinces, that we are ſurrounded by, and immerſed in, a fluid, which agitates bodies when it is in motion, which reſiſts the motions made in it, which ſuſtains bodies floating in it, and, in ſhort, which differs from the groſſer fluids, in few reſpects, except thoſe of tranſparency, elaſticity, and gravity; the two firſt of which properties it has, in a greater,

Elasticity of the Air.

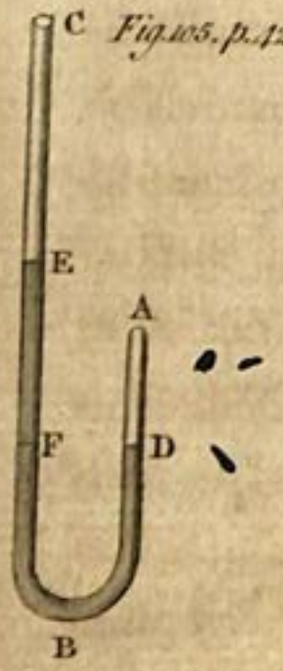
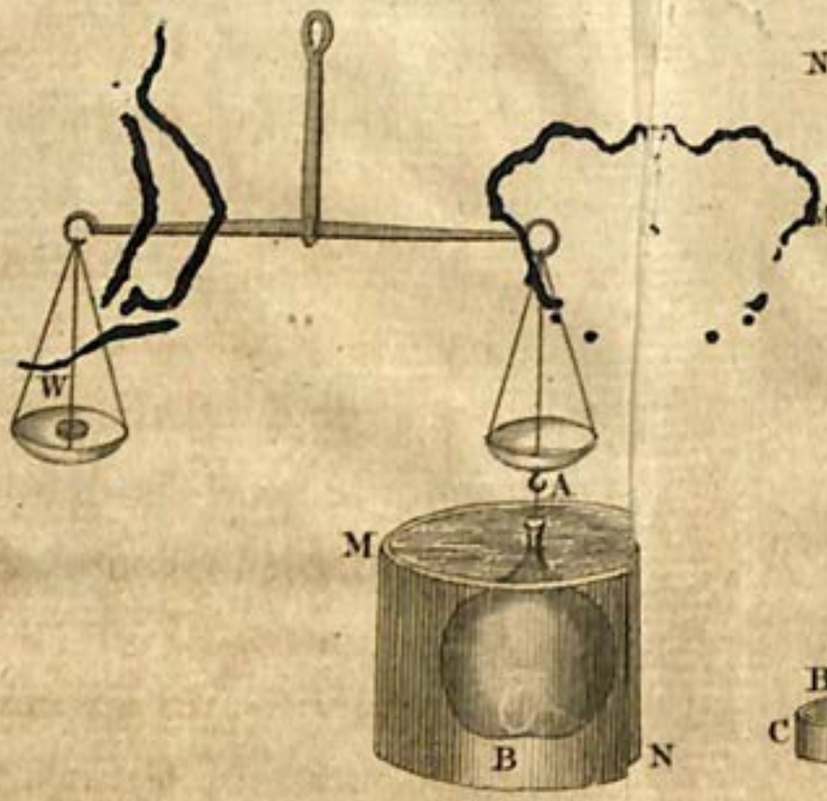
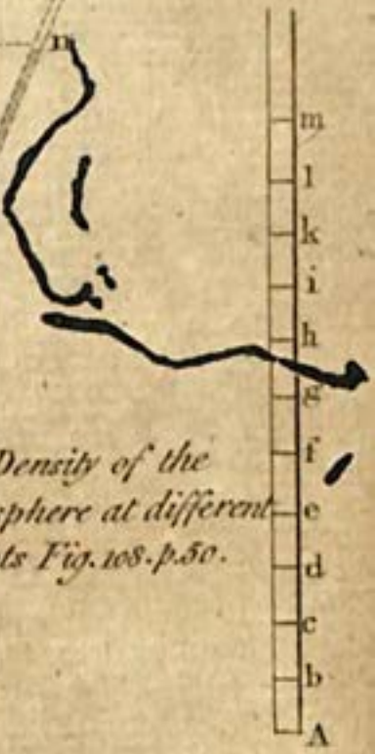


Fig. 105. p. 42.

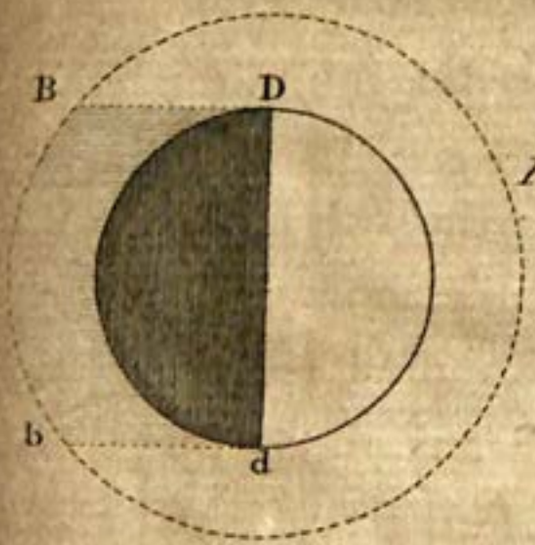
Weight of the Air Fig. 106. p. 44.



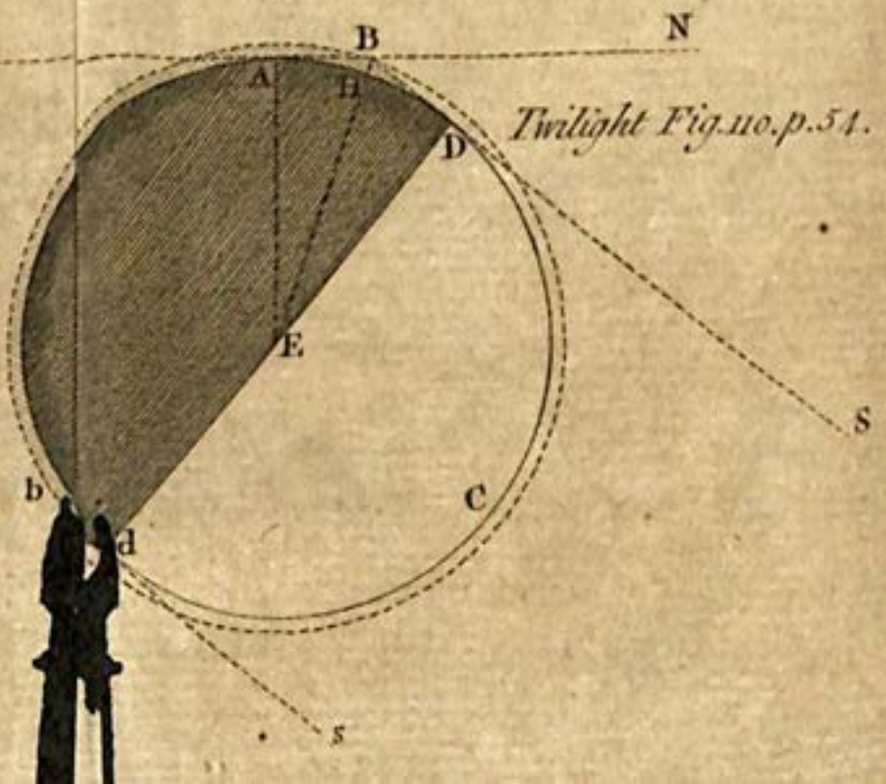
Torricellian Experiment Fig. [illegible] p. 45.



Density of the Atmosphere at different Heights Fig. 108. p. 50.



Twilight
Fig. 109. p. 54.



Twilight Fig. 110. p. 54.

greater, and the latter in a leſs degree than other fluids.

The whole maſs of this fluid, with its contents, is called the atmoſphere; which term is made uſe of when we conſider the effects which ariſe from its form, magnitude, denſity, &c. but when we ſpeak indefinitely of the fluid of which the maſs is compoſed, with a view to develope its qualities, and conſider it independant of the bodies which are immerſed in, or mixed with it, it is called the air, or air.

The philoſophers of antiquity claſſed the air among the elements or principles which enter into the compoſition of bodies, and the doctrine was long received by the moderns. At this day there are many who conſider pure air, that is, air which is not mixed with moiſture or the effluvia of bodies, as an uncompounded fluid; by which we muſt underſtand a fluid whoſe particles are uniformly ſimilar, and indeſtructible. For, if they be not uniformly ſimilar, it may be decompounded by the ſeparation of the particles of any one ſort; and if the particles be not indeſtructible, it may not only be decompound-

ed,

ed, but its properties entirely changed, by their comminution. Experiment does not confirm this opinion, for it is proved capable of decompoſition. But this is not our immediate purpoſe. It will be more regular to advert, in the firſt place, to the more obvious properties of the air, and afterwards enquire what it is that enters into its compoſition.

Air then is a fluid, whoſe particles are not in contact, and repel each other, which repulſion may be diminiſhed, but cannot be deſtroyed by any degree of cold that is known in the vicinity of the earth. For, if the particles were in contact the fluid could not be compreſſed, and if they did not repel each other, the fluid could not expand when the compreſſing force is removed: but this elaſticity is the property of the air, as may be ſhewn by various methods; one of the ſimpleſt of which is, to pour a quantity of quickſilver in the tube ABC (fig. 105.) which is cloſed at A, and open at C. Suppoſe the tube to be filled with quickſilver to E, then the air incloſed in the leg AB will prevent its riſing higher than D. Mark F in the ſame horizontal

zontal line with D, and by what has before been ſaid concerning hydroſtatics, the column DB will be in equilibrio with FB, and conſequently the quickſilver contained between F and D will not at all preſs on the air between A and D. But the column EF acting with its whole weight on the quickſilver between F and D cauſes it to preſs on the air at D, and condenſe it. By increaſing the quantity of quickſilver the condenſation is increaſed, and it is found, that the ſpaces into which the air is condenſed by different weights are inverſely as thoſe weights.

The latter part of the definition is that which diſtinguiſhes air from vapor, which is a fluid, the repulſion of whoſe particles may be deſtroyed by cold, and the whole condenſed into a groſs fluid by their coalition. Perhaps the difference between air and vapor may, in this particular, be much the ſame as between quickſilver and melted metal, lead, for inſtance; the former of which requires the moſt intenſe cold to reduce it to a ſolid form, while the latter is not exhibited in a fluid ſtate without the application of a very great degree of heat.

One

One of the firſt objects of enquiry that offer themſelves on this ſubject is the extent or magnitude of the atmoſphere. Experience aſſures us, that it is extended over the whole ſurface of the earth and ſea; and it is evident, from the ſuſpenſion and motion of the clouds, that its altitude is conſiderable; but the meaſure of this altitude muſt be obtained from its effects. Thus, if the ſpecific gravity of the air be found, and alſo its whole preſſure on bodies, it will be eaſy to diſcover the quantity and the height of the fluid. Another method of diſcovering the height of the atmoſphere is deduced from optical conſiderations, by obſerving the effect it has on the light of the Sun. We ſhall ſpeak of both in their order.

Let AB (fig. 106.) repreſent a bottle, whoſe contents are exactly known; for example, ſuppoſe it capable of holding two pounds of rain-water; let a valve, opening outwards, be fitted at A, and the air be exhauſted from within by means of the air-pump, hereafter to be deſcribed; let the veſſel thus exhauſted be weighed in * water, or any other denſe fluid,

* The intention of which is, that the ſcales being loaded as little as poſſible, may the more readily turn

in the veſſel MN, as repreſented in the figure, after which let the air be admitted. An additional weight of about $14\frac{1}{2}$ grains will be required to reſtore the equilibrium: therefore, the air contained in the veſſel AB weighs $14\frac{1}{2}$ grains, the proportion of which to two pounds is 1 to ·800, or $1\frac{1}{4}$ to 1000.

The ſpecific gravity of air being thus diſcovered, its preſſure may be found by the Torricellian experiment, ſo called from its inventor Torricellius. Let AB (*fig.* 107.) repreſent a glaſs tube of the length of 35 inches or upwards, cloſed at the end A, and open at B; fill the ſame with quickſilver, and cloſe the orifice at B with the finger, or otherwiſe: immerſe the end B in the veſſel of quickſilver CD, and remove the finger from the orifice; then the quickſilver will ſubſide to N in the tube at the height of about 30 inches.

In the infancy of the modern philoſophy, the ſolution of the cauſe of this phenomenon afforded matter for great controverſies; at preſent, the gravity of the atmoſphere being

with the leaſt alteration of weight; for the leſs they are loaded, the leſs is the friction at the fulcrum.

no longer in doubt with any that have at all attended to phyſiological ſubjects, it is readily explained on the common principles of hydroſtatics: for which purpoſe it muſt be remembered, that the preſſure, which a body, immerſed in the veſſel CD, would ſuſtain, is not only that which ariſes from the weight of the quickſilver, but likewiſe from that of a column of the atmoſphere, which is incumbent on its ſurface; ſo that every column of the quickſilver preſſes with a force that exceeds its own weight. When the tube is inverted into the veſſel of quickſilver, the ſurface of the column which it contains being defended from the preſſure of the atmoſphere, by the cloſure at A, can preſs downwards with no more than its own weight; and will, therefore, be in equilibrio with the preſſure which the quickſilver in the veſſel exerts againſt its deſcent, then only, when it is ſo much longer, that the additional quickſilver may be equal to the additional weight which a ſimilar column in the veſſel receives from the preſſure of the atmoſphere; that is to ſay, the preſſure of the atmoſphere on any given ſurface is equal to the weight of a column of

mercury,

mercury, whoſe baſe is the given ſurface, and height equal to that at which it ſtands in the Torricellian tube; and this preſſure is the weight of a column of air, whoſe baſe is the given ſurface, and height equal to that of the atmoſphere.

It has been ſhewn, that when the air is condenſed, its denſity is in the reciprocal proportion to the weight that compreſſes it. By means of the Torricellian tube we may obſerve, that the ſame ratio obtains when it is rarefied by taking off part of the weight of the ſuperincumbent atmoſphere. For, in any elaſtic fluid at reſt, the ſpring muſt equal the compreſſing force; and if any part of that force be taken away, it muſt expand till the ſpring becomes equal to the remainder; which will happen if the elaſticity of the fluid be weakened by expanſion. And ſince the preſſures of fluids are as their heights, the preſſure of the Mercury in the tube aB will be equal to that in the tube AB, when the mercury reſts at n in the ſame horizontal line with N. Now, if a bubble or ſmall quantity of air be admitted into the tube AB, it will depreſs the mercury below the mark N

till its ſpring and the weight of the mercury remaining in the tube be in equilibrio with the preſſure of the atmoſphere; that is, if the mercury be depreſſed to M, that part of the weight of the atmoſphere which correſponds with the quantity of mercury MB, will be ſuſtained by the weight of the mercury, and the remainder MN will be ſuſtained by the ſpring of the included air. The included air then, being preſſed by a weight leſs than that of the whole atmoſphere, becomes rarefied or expanded. By variouſly inclining the tube the included air may be made to bear more or leſs of the weight of the atmoſphere, (as may be gathered by meaſuring the perpendicular altitude of M above the ſurface of the quickſilver contained in the veſſel C D, and ſubtracting it from the altitude BN, which correſponds with the weight of the whole atmoſphere) and its contraction or dilatation obſerved: whence it appears, that the air, though greatly rarefied, occupies a ſpace which is reciprocally proportional to the compreſſing force.

If two columns of uniform fluids, whoſe ſpecific gravities differ, be equal in weight,

and

and ſtand on equal baſes, their heights will be reciprocally as their ſpecific gravities. The ſpecific gravities of quickſilver and air are reſpectively 14019 and $\frac{1}{1}$: therefore,

As the ſpecific gravity of air, - - - -		
Is to the ſpecific gravity of mercury, -	14019	
So is the height of the column of mercury, -	30	inches
To the height of an equal column of air	336456 or $5\frac{1}{4}$	Engliſh miles.

This would be the height of the atmoſphere, if it were uniformly of the ſame denſity; but as that is not the caſe, on account of the elaſticity which cauſes the upper parts to expand in proportion as the weight of the ſuperincumbent parts becomes leſs, as was before obſerved, the altitude muſt be much greater.

The denſity of the air in that part of the atmoſphere in which we live being ſhewn to be, in all caſes, as the weight that compreſſes it, it is plain, if the conſtitution of the air in the ſuperior regions be of the ſame kind, that its denſity at any altitude will be as the weight

or quantity of the ſuperincumbent air. Suppoſe Am (fig. 108.) to be a column of the atmoſphere, and imagine the ſame to be continued at pleaſure beyond m, ſo as to reach its utmoſt limits. Let this column be divided into an indefinitely great number of equal parts, Ab, bc, cd, &c. and the quantity of air contained in any one of thoſe parts, or its denſity, will be in proportion to the quantity of air which is ſuperincumbent on that part. Now, the difference between the quantities of air incumbent on any two contiguous parts is the quantity contained in the uppermoſt of thoſe parts; that is, for example, the quantity ſuperincumbent on d is leſs than that which is incumbent on c by the difference or part cd: therefore the quantities contained in the equal parts or diviſions are the differences between the incumbent maſſes of air taken in a regular ſucceſſion. And theſe quantities or differences have been ſhewn to be in proportion to the incumbent maſſes. * Now,

* Let a, b, c, d, &c. be magnitudes whoſe differences are as the magnitudes themſelves.

That is	$a-b : b :: b-c : c :: c-d : d$, &c.
Whence	$ac=bb$, $bd=cc$, &c.
Conſequently	$a : b : c : d$, &c.

it

it is demonstrable, that if any succession or series of magnitudes do increase or decrease in such a manner, that the differences shall be in proportion to the magnitudes themselves, then those magnitudes, and consequently their differences, shall be in a continued geometrical progression: whence it follows, that the densities or quantities of air contained in the equal divisions or parts Ab, bc, cd, &c. do decrease in a continued geometrical progression.

By a calculation instituted on these principles it is shewn, that the air at the height of seven miles above the earth must be $\frac{1}{4}$ of the density it is with us; at the heights of 14, 21, 28, and 35 miles respectively, $\frac{1}{16}$, $\frac{1}{64}$, $\frac{1}{256}$, and $\frac{1}{1024}$ of the density it is with us; and at the heights of 70, 40, and 210 miles respectively about $\frac{1}{1000000}$, $\frac{1}{1000000000000}$, $\frac{1}{1000000000000000000}$ of the same density; yet it does not follow from hence that the extent of the atmosphere is infinite; for at the extreme boundary, where there is no superincumbent fluid, the weights of the particles themselves, being finite, must prevent their resiling beyond a limited distance.

This reaſoning depends on the ſuppoſition that the ſuperior air is of the ſame conſtitution as that in which we live; but it muſt be confeſſed, that by the experiments which have been made on the air at the top of mountains, the preſſure ſeems to decreaſe in a higher proportion; ſo that the air in the upper regions muſt be more elaſtic than that near the ſurface of the earth, whoſe ſpring may perhaps be diminiſhed by various exhalations. To diſcover the circumſtances on which this difference of conſtitution depends, is an enquiry that well deſerves attention; and when the ſubject ſhall be farther elucidated, it is probable that the above ratios may, notwithſtanding, be applied with advantage.

Much pains have been taken to diſcover the cauſes which influence the altitudes of the mercury in the Torricellian tube at different heights above the ſurface of the earth. If this could be accurately done, it is plain that we ſhould have an eaſy method of meaſuring the heights of mountains, and other elevations. For the heights of the mercury being known, would indicate the correſpondent altitudes of the eminences on which the tube

tube was placed. And notwithſtanding all the difficulties which occur in the practice, this method of meaſuring heights is little inferior, if not even equal, to any other.

The other method of diſcovering the height of the atmoſphere is deduced from obſervations of the morning and evening twilight. Notwithſtanding the very great tranſparency of the air, it may be rendered viſible by means of the rays of light, which are incident on its particles, and thence reflected in all directions. This is evident from the appearance of the beams of the Sun admitted into a room through the window-ſhutter, and may frequently be obſerved when the Sun ſhines through the chaſms or openings in a dark cloud: whence it happens, that thoſe bodies which emit a very ſmall quantity of light are not to be diſcerned in this ſtronger light. In the day-time the ſtars are inviſible, and the flame of a candle can ſcarcely be ſeen in the ſun-ſhine: were it not for this illumination the ſky would appear black, and the ſhady ſides of objects would be of a dark colour, almoſt the ſame as at midnight.

The Sun ſhining on the globe of the earth can illuminate but one hemiſphere at once, as has already been ſhewn; but it is not ſo with the atmoſphere which environs the globe. Thus, the illuminated part of the globe terminates at D and d (fig 109.) but the atmoſphere is enlightened as far as B and b. In conſequence of which it happens, that thoſe parts which have already entered into the dark hemiſphere, and to whom therefore the Sun is ſet, do ſtill enjoy a degree of light which continues as long as any of the enlightened part of the atmoſphere remains in view. This light, which gradually decays after ſun-ſet, or increaſes before ſun-riſe, is called the twilight. Let AHDCdb (fig. 110.) repreſent a ſection of the earth in the plane of the Sun's azimuth, and let the ſpace contained between the concentric circles repreſent the atmoſphere: then, the Sun's rays in the directions SB, sb, will illuminate half the globe DCd, and the atmoſphere will be enlightened as far as B and b, on each ſide within the dark hemiſphere; which enlightened part, ſo long as it continues above the horizon of any place, will cauſe a twilight at that place.

place. The ray SDB is a tangent to the Earth at D, and meets the circumference of the atmoſphere at B. From B draw the line BH, a tangent to the Earth at A, which continue towards N; H N will then repreſent the horizon, in which the extreme point B of the enlightened part of the atmoſphere will be ſituated; that is, twilight will be juſt beginning or ending at the place A. The angle SBN, which is equal to the angle AED, will be the angle of the Sun's depreſſion beneath the horizon HN; and the angle AEB is the half of AED. Hence, if the depreſſion of the Sun beneath the horizon, and the ſemidiameter of the Earth be known, it will be eaſy to find the height of the atmoſphere. For, in the right angled triangle ABE,

As the ſine complement of
half the Sun's depreſſion AEB 8° 30′
Is to the Earth's ſemidiameter, AE 3437 miles,
So is radius ſine 90°
To the hypothenuſe EB 3475 miles.

The difference between which and the ſemidiameter of the Earth is the line HB or height of the atmoſphere, 38 geographical, or 44

Engliſh miles. The angle of the Sun's depreſſion is known by the time elapſed between the beginning or end of twilight, and the riſing or ſetting of the Sun; and it is judged to be twilight ſo long as the illumination of the atmoſphere prevents the ſmaller fixed ſtars from appearing. It is alſo obſerved, that the evening are always longer than the morning twilights, which muſt ariſe from the rarefaction of the air over the place, after the day's ſun-ſhine. A ſimilar difference is obſerved between the twilights of ſummer and winter.

CHAP. II.

Of the refractive Power of the Air; and of its Rareſaction and Condenſation by Heat and Cold.

THAT the celeſtial ſpace or heavens is either nearly or abſolutely vacuous, appears from the ſmall reſiſtance the planetary bodies ſuffer in their motions; ſuch reſiſtance, if it obtain at all, being too minute to be obſerved by any of the methods yet invented. Light therefore, when incident

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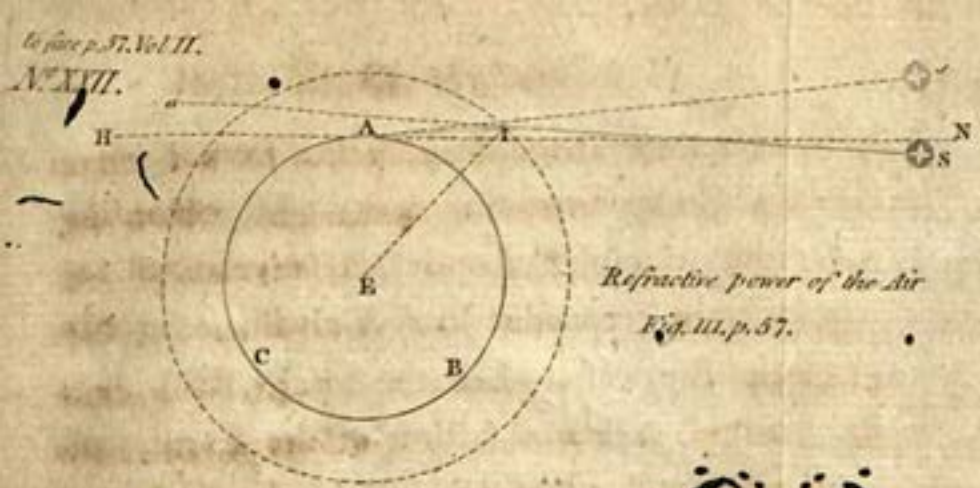


Refractive power of the Air
Fig. III. p. 57.

Spring of the Air
Fig. 112. p. 59.

Spring of the Air Fig. 113. p. 60.

Musical Chord Fig. 114 p. 84.

Syphon Fig. 116. p. [illegible].

Intermitting Spring Fig. 118 p. 92.

Thermometer
Fig. 118. p. 91.

The Pump Fig. 120. p. 93.

Mariners Compass. Fig. 117 p. 63.

Wind Gun Fig. 121. p. 93.

Fire Engine Fig. 119. p. 94.

Fountain by condensed Air
Fig. 122. p. 97.

dent on our atmoſphere, paſſes from a rarer to a denſer medium, and ought, according to the principles of optics, to be refracted towards the perpendicular. And this is accordingly the caſe. Let the circle ABC (fig. 111.) repreſent a ſection of the Earth, and the external concentric circle the ſurface of the atmoſphere; let HN be the ſenſible horizon of a place A, and S the Sun beneath the horizon; then a ray of light incident on the ſurface of the atmoſphere at I, will, inſtead of proceeding to a, be refracted towards the perpendicular IE, and that continually the more as the denſity of the medium becomes greater, ſo that it will arrive at A after paſſing through the curve IA; and a ſpectator at A will behold the Sun in the line of the laſt direction of the ray, namely in that of As, the tangent to the curve. The apparent elevation which a celeſtial body ſuffers when its rays fall with the greateſt obliquity, to wit, when it is ſeen in the horizon, is about thirty-three minutes of a degree: at other altitudes the differences between the true and apparent places are leſs, the incidences and refractions being leſs conſiderable.

Hence

Hence it comes to paſs, that we ſee the celeſtial bodies for ſome time after they are ſet, and before they riſe, in reality, by which means we enjoy about three days in the year more day-light than otherwiſe we ſhould: but in the northern parts, where the ſun riſes and ſets more obliquely, and the atmoſphere being condenſed by cold, refracts more ſtrongly, the difference is much greater.

The refraction, as well as all the other phenomena produced by the atmoſphere, are variable, as the denſity of the air changes. This variation renders the obſervation of low altitudes very uncertain, as the allowance for refraction cannot be collected with preciſion from any tables. On this account alſo, the trigonometrical admeaſurement of the heights of lofty mountains cannot be depended on to any degree of correctneſs.

It has been occaſionally remarked, that the air is condenſable by cold; but cold, as far as its properties are yet known, appears to be no more than the abſence or privation of heat, therefore the expreſſion will perhaps be more accurate, if we ſay that heat rareſies the air, or increaſes its elaſticity, and as a conſe-

quence

quence or converſe of the aſſertion ſay, that cold, or the privation of heat, ſuffers it to condenſe, or condenſes it, not by a poſitive action, but by the negation of the act of rarefying. But theſe diſtinctions in expreſſion are of no great importance, provided we do not pervert the ſenſe, and take words for things, as is too often the caſe in philoſophical, as well as other reſearches. The increaſed ſpring of the air by heat is proved by the following experiment.

Let ADB (fig. 112.) repreſent a hollow glaſs ball, to which is affixed the narrow bent tube ACGE. The lower part of the bent tube and part of the ball is filled with mercury, as in the figure, the ſurface AB within the ball being on the ſame horizontal line with the ſurface at C in the tube. The parts of the mercury will then be in equilibrio, the external ſurface C being preſſed by the weight of the atmoſphere, and the internal ſurface AB being preſſed by the ſpring of the included air, which is equal to that weight. But if the ball be immerſed in boiling water, the increaſed ſpring of the included air preſſing on the ſurface AB, will raiſe the mer-

cury from C to G, and there ſuſtain it, namely, at the height of 8 ½ inches, when the mercury in the Torricellian tube ſtands at 30 inches. And as the contained air is not ſenſibly dilated by the extruſion of ſo ſmall a quantity of mercury, the ſuſtentation may be regarded as the entire effect of its ſpring. The ſpring of the included air at the heat of boiling water is therefore not only equal to the weight of the atmoſphere, but likewiſe to an additional preſſure of more than ⅓ of that weight.

By the ſame inſtrument, it is found, that the air is contracted in its dimenſions by immerſion in very cold or freezing mixtures. And concluſions ſimilar to theſe may be made by various methods, which the attentive learner will readily diſcover.

In the foregoing experiment the air was prevented from expanding, in conſequence of its increaſed ſpring, by the preſſure of the mercury, but if the tube AB (fig. 113.) which is cloſed at B, and open at A, a ſmall quantity of mercury C being admitted, which incloſes the air between C and B, be immerſed in boiling water, the included air CB is found

by the motion of the mercury at C to be expanded in the proportion of 3 to 2 beyond its bulk at freezing cold. By this means it is found, that the greateſt difference of the expanſions of the air in ſummer heat, and the cold of the air when water is beginning to freeze, is as thoſe of the numbers 7 and 6. In theſe experiments, if there be any moiſture in the included air, a much greater degree of dilatation follows; for the expanſion of vapours by heat is much more conſiderable than that of the air itſelf.

It will be eaſy from the above, to indicate the cauſes of many phenomena that happen in the air. For, if any part of the air be heated, it will expand, and in conſequence of that expanſion, become ſpecifically lighter than before. It muſt, therefore, by the laws of hydroſtatics, aſcend, and the circumambient air muſt preſs in on all ſides to ſupply its place. Hence the cauſe of the aſcent of ſmoke in a chimney. The air which paſſes through the fire, or comes within a certain diſtance from it, is rarefied, and aſcends, giving place to the cold air which preſſes in; this in its turn becomes rarefied, and the aſcending

aſcending current of air continues as long as the fire is kept up, the wind drawing from all parts towards the chimney, as experience teſtifies.

If the fire were in the open air, the heated air would ſtill aſcend in a current, and the cooler air preſs in on all ſides; that is to ſay, a wind would be generated, which would conſtantly blow towards the fire. The quantity of air, which is rarefied by any fire we can make, is ſo ſmall, that the wind produced by that means is too inconſiderable to be perceived at any great diſtance from the fire; but the rarefactions which ariſe from natural cauſes are ſufficient to produce all the winds with which the atmoſphere is agitated.

CHAP.

CHAP. III.

Of Winds, and their Cauſes.

BEFORE we proceed to deſcribe and account for the winds which are obſerved in the atmoſphere, it will be neceſſary to premiſe, that the ſenſible horizon is not only divided into 360 degrees, like other great circles, but alſo into 32 equal parts, which are called points of the compaſs, which points are again ſubdivided into halves and quarters. The points of the compaſs have each a ſeparate name. Thoſe points in which the meridian interſects the horizon, are termed North and South; and two other points, at the diſtance of 90° from the North and South, are termed Eaſt and Weſt: theſe four are denominated cardinal points. The intermediate points take their names from the cardinal points between which they are ſituated as in the figure, where the initial letters N. S. E. W. (fig. 117.) ſtand for the words North, South, Eaſt, Weſt.

A wind

A wind is named from the point of the compaſs from which it blows.

The different winds may, with reſpect to their direction, be reduced into three claſſes; viz. general, periodical, and variable winds.

General winds are thoſe which blow always nearly in the ſame direction. In the open ſeas, that is, in the Atlantic and Pacific Oceans, under the equator, the wind is found to blow almoſt conſtantly from the eaſtward; this wind prevails on both ſides of the equator to the latitude of 28°. To the northward of the equator, the wind is between the North and Eaſt, and the more northerly the nearer the northern limit; to the ſouthward of the equator, the wind is between the South and Eaſt, and the more ſoutherly, the nearer the ſouthern limit.

Between the parallels of 28 and 40 ſouth latitude, in that tract which extends from 30° Weſt to 100° Eaſt longitude from the meridian of London, the wind is variable, but by far the greater part between the N. W. and S. W. ſo that the outward bound Eaſt India

India ſhips generally run down their eaſting on the parallel of 36° ſouth.

Beyond the northern limit of the general wind in the Atlantic Ocean, the weſterly winds prevail, but not with any certainty of continuance.

Near the weſtern coaſt of Africa, within the limits of the general wind, the winds are found to be deflected towards the ſhore, inſomuch that they are found to blow from the N. W. and S. W. quarters for the moſt part, inſtead of the N. E. and S. E. as is the caſe farther out at ſea.

The general winds are uſually called trade-winds.

In the Atlantic Ocean, the S. E. trade-wind extends as far as 3° north, and the N. E. trade-wind ceaſes at the 5th degree N. In the intermediate ſpace are found calms with rain and irregular uncertain ſqualls, attended with thunder and lightning. But this ſpace is removed ſomewhat farther to the northward or ſouthward, according as the Sun's declination is more northerly or ſoutherly.

Periodical winds are thoſe which blow in a certain direction for a time, and at ſtated

ſeaſons do change and blow for an equal ſpace of time from the oppoſite point of the compaſs. Theſe may be divided into two claſſes; viz. monſoons, or winds that change annually; and land and ſea breezes, or winds that change diurnally.

While the Sun is to the northward of the equinoctial, that is to ſay, in the months of April, May, June, July, Auguſt, and September, the wind blows from the ſouthward over the whole extent of the Indian Ocean; namely, between the parallels of 28° N. and 28° S. latitude, and between the eaſtern coaſt of Africa, and the meridian which paſſes through the weſtern part of Japan. In the ſea between Madagaſcar and New Holland, the S. E. wind prevails as far as the equator, where it deflects and blows into the Arabian Gulf and Bay of Bengal from the S. W. Between Madagaſcar and the main land of Africa, a S. S. W. wind obtains and coincides with the S. W. winds in the Arabian Gulf. To the northward of New Holland, the S. E. wind is predominant, but varies very much among the iſlands; and between the peninſula of Malacca and the Iſland of Japan, a S. S. W. wind

W. wind prevails. All this is to be underſtood for the aforementioned months.

But in the other months, October, November, December, January, February, and March, a remarkable alteration takes place. In the ſea between Madagaſcar and New Holland, the S. E. wind extends no farther to the northward than about the 10th degree of ſouth latitude, the other 10 degrees being occupied by a wind from the oppoſite point of the compaſs, or N. W. at the ſame time that the winds in all the northern parts of the Indian Ocean ſhift round, and blow directly contrary to the courſe they held in the former ſix months. Theſe winds are called monſoons, or ſhifting trade-winds.

Theſe changes are not ſuddenly made. Some days before and after the change, there are calms, variable winds, and dreadful ſtorms, attended with thunder, lightning, and rain.

On the greater part of the coaſts of lands ſituated between the tropics, the wind blows towards the ſhore in the day-time, and towards the ſea in the night. Theſe periodical winds are termed the land and ſea breezes, and are much affected, both in their

direction and return by the courſes of rivers, tides, &c.

Variable winds are thoſe which are ſubjected to no period, either in duration or return, and are too well known to need deſcription.

In our attempts to explain thoſe appearances, it will be neceſſary to conſider what may be the cauſes of wind in general, and afterwards, as far as obſervation enables us, to apply the reſult to the ſolution of particular caſes.

If the air were uniformly of the ſame denſity at the ſame height, and the lighter parts always repoſed upon the heavier, it is evident that, the lateral preſſure being equal in every horizontal direction, it would remain at reſt. But, on the contrary, if any portion or part of the air were heavier than the reſt, it would deſcend, or if lighter, aſcend, till the equilibrium was reſtored; and, in the firſt caſe, the air diſplaced would occaſion a wind, diverging as it were from a central ſpace, and in the latter, the air ruſhing in, would occaſion an appearance quite contrary, namely, a wind converging to a central ſpace. Hence it appears,

that

that any agent that alters the denſity of part of the air will produce a wind.

Experience has ſhewn no more than two methods by which the denſity of the air may be altered, namely, the application of compreſſion, or of heat. The compreſſion which the air ſuffers in the natural courſe of things, is at all times nearly uniform and the ſame, and conſequently can produce no motion in the atmoſphere. It remains, therefore, to be conſidered in what manner the air is affected by the heat which it ſuffers at different times and ſeaſons.

If the Earth did not revolve on its axis, it is plain, that the Sun, being ſtationary over one particular ſpot, would rarefy the air at that ſpot: it would conſequently aſcend by the preſſure of the circumambient and leſs rarefied air, till it arrived at a region in which the air was ſufficiently rare to ſuffer it to expand on all ſides: and thus there would be produced a converging wind near the ſurface of the Earth, and a contrary or divergent wind in the upper region of the air. But ſince the Earth does revolve on its axis, and the Sun therefore is not ſtationary,

it follows, that the place at which the air is moſt rarefied will be found ſucceſſively in every point of the parallel over which the Sun moves in the courſe of a day. And as this place continually moves to the weſtward, the lower air muſt as conſtantly follow it. Hence we have the origin of the general N. E. and S. E. trade-winds, which no doubt would extend over the whole of the ſpace between the tropics, were it not for the different temperatures of the continents and iſlands over which the Sun paſſes. For the ſurface of earth is more heated than that of the ſea, by reaſon that the tranſparency of the water permits many of the rays of light to paſs to its interior parts before they are ſtifled and loſt. The air therefore, which is contiguous to the land, being more heated than that which reſts upon the ſea, will prevent the regularity of the effect. Thus, near the weſtern coaſts of Africa and America, the winds blow from the weſtward, to ſupply the conſtant rarefaction which thoſe heated lands produce.

The

The general N. E. and S. E. trade-winds producing in the upper region of the air winds in the contrary directions, ſeem to be the cauſe of the weſterly winds which are obſerved to prevail between the latitudes of 28° and 40°.

In accounting for the monſoons, or periodical trade-winds, it is neceſſary to mark the peculiar circumſtances which obtain in the Indian Ocean, and which are not found in the Atlantic or Pacific Oceans. They ſeem to be theſe. That the ocean is bounded to the northward by ſhores, whoſe latitude does not exceed the limits of the general trade-wind, and that the general trade-wind falls on lee-ſhores to the weſtward.

The Sun being twice in the year vertical in the equator, and never departing more than 23 ½° from thence, cauſes the air that climate to be hotter than at any other place on the ocean; and is the occaſion of the trade-wind, as has already been ſhewn. Such a rarefied ſpace muſt extend acroſs the Indian Ocean, and produce a S. E. wind to the ſouthward, and a N. E. wind to the northward of the equator, over which in the upper

regions of the air, the winds return in the contrary directions. This we accordingly ſee happens in the months of October, November, December, January, February, and March. But when the Sun declines to the northward, and heats the lands there ſituate, the air contiguous to thoſe lands becomes rarefied, and the lower air has a tendency to move that way. This tendency increaſes as the Sun advances farther North, inſomuch that the whole body of the lower air to the northward of the equator moves thither, notwithſtanding the equatorial rarefaction; which muſt be ſupplied by the upper or returning current. So, that the body of the lower air in the northern part of the Indian Ocean is determined as to its courſe by the greater rarefaction: if the rarefaction at the ſurface of the land be greater than that at the equator, the wind blows to the North, and the contrary happens when the equatorial rarefaction is greateſt. When the northerly trade-wind prevails, it blows out of the Arabian Gulf upon the coaſts of Arabia, Aynan and Zanguebar, and is reflected into the ſtraits of Moſambique. And at the other ſeaſon, the general

general ſouther[illegible] wind ſeems to be reflected to the weſtward by the ſame cauſe.

Theſe, or ſome ſuch like, are probably the cauſes of the winds which prevail in the Indian ſeas. But the obſervations we are in poſſeſſion of are too few and too inaccurate for the purpoſe of forming a theory. To which may be added, that all the atmoſpherical appearances ſeem to depend on ſo many, till of late unregarded cauſes, particularly the operation of electricity, that to inveſtigate them more minutely would require a ſeparate volume.

After what has been ſaid, it will not be difficult to account for the land and ſea breezes. For the land being heated in the day-time, the wind blows in ſhore to ſupply the place of the aſcendent rarefied air: and in the night the land cools, and condenſes the air, occaſioning the land breeze.

The circumſtances on which the variable winds depend, are referable to thoſe already noticed, but act ſo differently in particular caſes, that our limits do not admit of an attempt to reduce them to rule.

When

When ſeveral winds converge ſwiftly to one point, the air aſcends with great rapidity, and acquires a whirling motion, like that of water deſcending in a funnel. And as the centrifugal force in this whirling motion of the water is often ſufficient to counterpoiſe the lateral preſſure, and to prevent its approaching the central part, it frequently happens, that a perforation is ſeen quite through the body of the fluid. In like manner, the centrifugal force of the air may become equal to the preſſure of the atmoſphere, and conſequently leave a void ſpace about the center of the motion. This phenomenon is called a whirlwind, and ſometimes produces fatal effects. For, partly by the expanſion of the air included in houſes or other buildings, and partly by the violence of the aſcending current, it happens, that bodies near the center of the whirl are blown up into the vacuum, or carried aloft with great impetuoſity in a ſpiral motion.

If one of theſe whirlwinds happen at ſea, the preſſure of the atmoſphere being taken off that part of the ſurface over which the va-

cuum

cuum is formed, the water, on the principle of the Torricellian tube, will riſe to the height of thirty-two or thirty-three feet before it will be in equilibrio with the external preſſure. The aſcending warm air being moſt probably charged with vapours, will ſuffer them to be condenſed as it arrives in a colder region, and thus the courſe of the current will be marked by the denſe and opake vapor, and by the continual aſcent a cloud will be formed above. Theſe are the phenomena of water-ſpouts. At firſt a violent circular motion of the ſea is obſerved for a ſpace ſometimes of twenty feet diameter; after which the ſea riſes by degrees into a ſolid tapering column of about thirty feet in height, at the ſame time that a cloud appears, from which a dark line or column deſcends. This column is met by another, which aſcends ſomewhat like ſmoke in a chimney, from the lower or ſolid part of the ſpout. After this junction the cloud continually increaſes till the whirl ceaſes, and the appearance terminates.

But though water-ſpouts undoubtedly depend in a great meaſure on the convergence and circular motion of winds; yet, as we

have

have already had occaſion to remark concerning the trade-winds, it is probable that other unheeded cauſes concur in producing the appearance.

CHAP. IV.

Of Sound; and of Muſic.

IN ſpeaking of the reſiſtances which bodies ſuffer when moving in fluids, we obſerved that obtuſe bodies moving in elaſtic fluids condenſe that part towards which they move, at the ſame time that the part from which they recede is rarefied. This condenſation or rarefaction muſt produce an undulatory or vibrating motion in the fluid. Thus, if a body by percuſſion or otherwiſe be put into a tremulous motion, every vibration of the body will excite a wave in the air, which will proceed every way in a circular motion, and the quicker the vibrations of the body ſucceed each other, the leſs will be the diſtance between each ſucceſſive wave. It is alſo * demonſtrated, that the velocity with

* Princip. 47. l. 2.

which

which a wave moves from the tremulous body in an elaſtic fluid, whoſe denſity is in proportion to its compreſſion, is uniform and the ſame, whether the interval between the waves in ſucceſſion be leſs or greater.

The ſenſation which is excited in the mind by means of theſe waves which enter the ear, and produce a like motion in a thin membrane, that is ſtretched obliquely acroſs the auditory paſſage, is called ſound. But in vulgar language the term is uſed to imply not only the ſenſation excited in the mind, but likewiſe the affection of the air, or of the ſonorous body by which that ſenſation is produced. Thus, we ſay, that a ſound is in the air, or that a body ſounds when ſtruck, though the affection of the air or body is very different from the ſenſation. We have ſeveral times had occaſion, in defining the philoſophical uſes of terms, to obſerve the imperfections of common ſpeech. Preciſion and accuracy render it neceſſary. When, therefore, we ſay, a body ſounds, it muſt be underſtood that the body or its parts vibrate ſo as to occaſion waves in the air; when we ſay a ſound flies or paſſes in the air, it muſt be underſtood that

a ſyſtem

a ſyſtem of waves, produced by a like number of vibrations in a ſonorous body, proceed every way in circles from that body; and when we ſpeak of ſound abſtractedly, we muſt be underſtood to mean, that theſe two acts taking place do, by means of the ear, occaſion an idea or ſenſation in the mind.

That ſonorous bodies do move or tremble, ſcarce needs any illuſtration: it is evident in drums, bells, and the like, whoſe vibrations being large and ſtrong, are therefore more perceptible: and that a ſimilar vibration is excited in the air, is plain from the motions produced in bodies that are adapted to vibrate in coincidence with the ſonorous body.

Since the waves, in all caſes, move with an uniform and equal velocity, it follows that all ſounds, loud or low, acute or grave, muſt arrive at the ear in equal times from ſonorous bodies equally diſtant. This is confirmed by experience; for all ſounds are found to move 1142 Engliſh feet in a ſecond of time. The knowledge of the velocity of ſound is of good uſe for determining diſtances of ſhips, or other objects: for inſtance, ſuppoſe a ſhip fires a gun, the ſound of which is heard 5 ſeconds after

after the flash is seen; then, 1142 multiplied by 5, gives the distance, 5710 feet, or 1 English mile and 430 feet.

When the waves meet with an obstacle which is hard and of a regular surface, they are reflected, and consequently an ear placed in the course of these reflected waves will perceive a sound similar to the original sound, but which will seem to proceed from a sonorous body, situated in like position and distance behind the plane of reflection as the real sonorous body is before it. This reflected sound is called an echo.

The waves of sound being reflexible nearly the same in effect as the rays of light, may be deflected or magnified by much the same contrivances as are used in optics, though the continual decrease in the force of the waves as they expand, by which sound constantly decays as the distance from the sonorous body increases, makes a considerable difference in the phenomena. From this property of reflection it happens, that sounds uttered in one focus of an elliptical cavity are heard much magnified in the other focus: instances of which are found in several domes and vaults, particularly the whispering gallery, which runs

round the lower part of the circular dome at St. Paul's Cathedral in London, where a whiſper uttered at one ſide is reflected to the other, and may be very diſtinctly heard. On this principle alſo is conſtructed the ſpeaking trumpet, which either is or ought to be a hollow parabolic conoid, having a perforation at the vertex, to which the mouth is to be applied in ſpeaking, or the ear in hearing.

Beſides the advantages we enjoy from the exiſtence of ſound, in advertiſing us of danger, and the like, from without, when the ſenſe of ſeeing ceaſes to be uſeful, and in conveying our thoughts to each other by means of the aſſociation which we form between words and ideas, there is another benefit which ariſes from the pleaſure we receive, from that combination of ſound which is known under the name of muſic. This pleaſure is ſo great, that in all nations and ages muſic has formed the chief part of the idea of that bliſs which awaits the virtuous in a future ſtate. To thoſe who feel themſelves enlivened at the jocund ſtrain, or whoſe hearts overflow at the plaintive and melancholy note, no proof will be neceſſary to ſhew that this delightful

ſcience

ſcience can command the affections: and if there be any ſuch as are callous to the impreſſions of this nobleſt ſource of pleaſure, the attempt would be vain, for no words can convey an adequate notion of its effects.

In the ſpring ſeaſon of the year, when the whole face of Nature puts on the appearance of renewed life and vigour; the birds begin to tune their irregular melody. The mind of man naturally expands with delight at the pleaſing ſcenes about him, of which the animated part attracts the moſt attention. For this reaſon he aſcribes that pleaſure to the muſic of the feathered race alone, which in reality is the effect of the whole ſcene. With equal propriety he might aſcribe it to the whiſtling plowman, the lowing ox, or the bleating lamb. Images that contributed perhaps at leaſt an equal ſhare to his pleaſure. Hence probably originated the notion, that the invention of muſic aroſe from an imitation of the birds, though the vaſt ſuperiority of the human muſic is ſufficient to overthrow ſuch a poſition. The birds are muſical by nature, and man is much more ſo by the

ſame cauſe. To reſolve the effect of an evident natural endowment into imitation, muſt therefore ariſe from a deſire of ſyſtematizing, rather than a wiſh to develope the truth. As the earlieſt language muſt have been ſimple and unartificial, and refined by degrees, ſo the earlieſt muſic muſt have been rude and incorrect, conſiſting rather of a wild, though pleaſing, melody, than bearing any great reſemblance to the compoſitions of modern times, which have all the advantage of ſubſequent obſervation and improvement. But as theſe ſpeculations do not ſo immediately tend to our preſent purpoſe, we will advert to thoſe circumſtances of ſound in which muſic conſiſts.

If a body be ſtruck, and the vibrations excited be iſochronous and ſimple, the undulations produced in the air muſt be ſo likewiſe, whence there will be produced a ſimple and uniformly ſimilar ſound, except as to loudneſs or intenſity; for, as the vibrations grow leſs ſtrong, the ſound decays; but if the vibrations excited be various and diſſimilar, a like variety of diſſimilar undulations will be produced

in

in the air; and the ſound muſt be harſh, as if ſeveral ſounds were heard together. The firſt of theſe ſounds is a muſical tone, and the latter a noiſe.

This is evident, becauſe we find that thoſe bodies which are the moſt uniform in their texture, and by conſequence beſt adapted to vibrate ſimply and iſochronally, do produce the moſt muſical tones; as for example, maſſes of elaſtic metal, braſs, caſt-iron, and the like. And this tone is more ſtrictly muſical if the metal be ſo formed as to vibrate in the ſimpleſt manner poſſible. Thus, a hollow metallic veſſel or bell, if it be well formed, and not damaged in the tuning, will give but one uniform muſical tone, or at leaſt the tones produced will conſiſt of one predominant or principal one, and ſeveral others which have a perfect muſical agreement with it: a wire of an uniform thickneſs, ſtretched over two hard bridges or fulcrums, will produce the ſame effect. Brevity obliges us to paſs over the various means by which muſical tones may be obtained, and to attend only to thoſe which are produced by ſtrings or wires, as being the moſt ſimple.

Experience and reaſon have eſtabliſhed the following poſitions reſpecting the vibrations of chords or ſtrings.

The forces or weights which are neceſſary to draw an extended chord AB (fig. 114.) out of its place to the diſtances Ce, Cf, Cg, are directly proportional to thoſe diſtances, provided the chord be not too much drawn aſide.

Therefore, ſince the forces with which the chord returns to its firſt ſituation, when ſet at liberty, are always in proportion to the ſpace it has to paſs through, the vibrations muſt all be performed in equal times.

If chords differ only in thickneſs, the times of their vibrations will be directly as their diameters.

If chords differ only in tenſion, the times of their vibrations will be inverſely as the ſquare roots of the weights by which they are ſtretched.

If chords differ only in length, the times of their vibrations will be directly as their lengths.

That tone which is produced by a ſtring that vibrates quickly is termed acute or ſharp, when compared with the tone of a ſtring that

vibrates ſlower; and the tone produced by the latter is called grave or flat, when compared with that of the former.

If two chords be ſtruck, either at the ſame inſtant or in immediate ſucceſſion, the coincidence of ſound is pleaſing or diſpleaſing according as the two tones produced ſtand related to each other in gravity or acuteneſs: if they be ſo related as to afford pleaſure, the coincidence is called a concord, but if not, it is termed a diſcord.

A ſet of tones which follow each other, and afford pleaſure, is called melody; a ſet of cotemporary tones, which afford pleaſure, is called harmony.

The more frequently the vibrations of two chords do coincide with each other the perfecter the concord will be; thus, two equal ſtrings, equally ſtretched, will each give the ſame tone; the vibrations of the one will coincide with thoſe of the other, and the concord will be moſt perfect: again, two ſtrings, which differ only in length, the one being half the length of the other, will vibrate the one twice while the other vibrates once, the coincidence will be at every ſecond vibration

of the ſhorter ſtring, and a concord will be produced, but leſs perfect; if the ſtrings be in length as 2 to 3, the coincidence will be leſs frequent, namely at the third vibration of the ſhorter ſtring, and the concord will be ſtill leſs perfect: and ſo forth.

On this principle, and by the help of the foregoing ratios, are conſtructed all ſtringed inſtruments; that ſeries of muſical tones being ſelected, which experience has ſhewn to be beſt adapted for the purpoſes of melody and harmony. The ſeries is called the diatonic ſcale, and its properties, together with the names of the tones, may be ſeen in the following ſcheme:

Names.	Lengths.	Perfection.
Uniſon, or fundamental	1 : 1	Moſt perfect concord.
Second - -	10 : 9	Diſcord.
Third greater	5 : 4	Imperfect concord.
Fourth - -	4 : 3	Imperfect concord.
Fifth - -	3 : 2	Perfect concord.
Sixth greater	5 : 3	Imperfect concord.
Seventh greater	15 : 8	Diſcord.
Octave - -	2 : 1	Perfect concord.

The above is called the ſharp ſeries, in contradiſtinction to the flat ſeries, or ſcale in which

which the third, ſixth, and ſeventh are leſs or flat, being in the ratios of 6 : 5, 8 : 5 and 9 : 5; beſides which, in practice there are other intermediate tones uſed as the ſecond leſſer and fourth greater, which are in length as 16 : 15, and 7 : 5; all theſe are found in the conſtruction of inſtruments; that by their means the performer may place his fundamental, or principal note, on any of the tones at pleaſure, and uſe the other tones which ſtand in the above relations to it; they being ſufficiently near for practice, though not ſo perfectly accurate as in that ſeries for which the inſtrument is formed.

The notation of muſic, and the relations which the different ſcales bear to each other, together with the reſt of the particulars on which the rules for compoſition and accompanyment depend, require too copious an explanation to be admitted in this place: we therefore diſmiſs the ſubject, and proceed to give an account of the inſtruments whoſe conſtruction depends on the ſpring or weight of the air.

CHAP. V.

A Deſcription of various Inſtruments, whoſe Effects depend on the Properties of the Air.

THE mercury in the Torricellian tube ſtands at the height of about thirty inches, by means of the preſſure of the air, as has already been obſerved: we have alſo ſeen, in conſidering the phenomena of winds, that this preſſure is not every where alike, nor always the ſame at any particular place. In conſequence of which it happens, that the mercury in the Torricellian tube does not preſerve the ſame invariable altitude: for, when the air at any place is denſe, the mercury ſtands at a greater height than when it becomes lighter: thus the tube becomes an inſtrument to indicate the varying weight of the atmoſphere, and when fixed in a proper frame with graduations to meaſure the altitude of the mercury, is known by the name of the barometer. The variations are between the altitudes of $27\frac{1}{2}$ and $30\frac{1}{2}$ inches.

The

The inſtrument deſcribed at p. 59. is alſo uſed for the ſame purpoſe, under the name of the marine barometer, it being uſeful at ſea, where the common barometer is of little ſervice, on account of the ſhip's motion, which cauſes the mercury to librate up and down in the tube. But as this barometer is ſubject to alteration, on account of heat and cold, as well as on account of change in the weight of the air; and as the diſtinguiſhing the effects of each is attended with ſome little trouble, it is not much in uſe on ſhore.

There are many contrivances for enlarging the diviſions on the barometer, ſuch as inclining the tube, and the like; but they are all ſubject to inconveniences, on account of friction, which the upright barometer is free from, and are therefore not much in requeſt.

In the ſecond chapter of the preſent ſection it was obſerved, that the air is condenſed or rarefied by heat and cold. On this account it was formerly made uſe of to indicate the varying temperature of the weather in thoſe reſpects: for the marine barometer is a thermometer, and its variations being occaſioned by a twofold cauſe, it is not with facility applied

applied to either purpoſe. The thermometer, or inſtrument by which the degrees of heat and cold are denoted, is therefore conſtructed by the uſe of other fluids, though the air-thermometer is not without its convenience for diſtinguiſhing very ſmall differences in heat and cold, which are not ſhewn by thoſe inſtruments which are made to ſuit a more extenſive purpoſe.

The property of being expanded by heat, and contracted by cold, is not peculiar to air. All bodies whatſoever are ſubject to the ſame, though not equal, mutations; unleſs we may except ſome fluids, as water, &c. which ceaſe to contract when the degree of cold is ſo great as to freeze them, inſtead of which they are conſiderably dilated when in the form of ice: it is probable that this laſt circumſtance ariſes from the expanſion of the fixed air, which lies dormant till extricated by the cold. As the preſſure of the atmoſphere is not conſiderable enough to alter the dimenſions of denſe bodies in any ſenſible degree, it is plain that their mutations will indicate the effects of heat alone, and conſequently they muſt be very

very proper for the matter of thermometers: and as theſe mutations are very ſmall in proportion to the whole bulk, ſolid bodies muſt be inconvenient for the purpoſe, on account of the great length required to make them perceptible: but in fluids, by means of proper veſſels, it will be eaſy to render the leaſt alteration viſible; for if the neck or ſtem of any glaſs-veſſel be very ſmall in proportion to the contents of the bulb or bottle, the leaſt expanſion of the included liquor will occaſion a viſible riſe in the neck. Thus, AB (fig. 115.) repreſents a glaſs-tube, whoſe end A is blown into a ball: this ball, and part of the tube, being filled with quickſilver, the leaſt change of the bulk of the quickſilver, and conſequently of the temperature of the circumambient air, or contiguous bodies, is ſhewn by a riſe or fall of the ſurface in the tube; the quantity of which is indicated by the ſcale ab, affixed to the frame of the inſtrument.

If the bent tube CED (fig. 116.) be filled with water, and the ſhorter leg EC immerſed in the water contained in the veſſel AB, the water will all flow out at the aperture D, and the veſſel will be emptied. For the preſſure

on

on the aperture C is equal to the weight of the atmoſphere, and is counteracted by the weight of the column EC, and the preſſure on D is the ſame weight, but counteracted by the column ED. And as ED is longer than EC, the preſſure of the atmoſphere on D will be leſs effectual than that on C; conſequently the water will flow out at the orifice D, receding from the greater preſſure. This inſtrument is called a ſyphon, and is ſometimes uſed to draw liquors out of caſks that are ſo placed as not conveniently to be moved.

A very probable account of the cauſe of intermitting ſprings may be given on the principle of the ſyphon. For, let GFC (fig. 118.) repreſent a cavity or receptacle in the bowels of a mountain, from the bottom of which C, proceeds the irregular cavity or ſyphon CED: then, if by ſprings or otherwiſe the receptacle begin to fill, the water will at the ſame time riſe in the leg CE of the ſyphon till it has attained the horizontal level HH: after which, it will begin to flow out by means of the leg ED, and will continue to increaſe in the quantity diſcharged, as the water riſes ſtill higher, till at length the

ſyphon

ſyphon will emit a full ſteam, and by that means empty the receptacle. At this period the ſtream will ceaſe, till the receptacle being again filled, will again exhibit the ſame appearance. And theſe periodical returns of flood and ceſſation will be regular, if the filling of the reſervoir be ſo; but the interval of the returns muſt depend on the dimenſions of the apparatus, and the quantity of influent water.

The action of that very uſeful inſtrument the pump, depends on the preſſure of the atmoſphere. It conſiſts of a pipe CD (fig. 119.) whoſe lower end C is immerſed in water: at B is fixed a clack or valve opening upwards, and in the ſuperior part of the tube is worked a piſton A, which by means of leather, fits very cloſely in the pipe. In this alſo is a valve opening upwards. Now, if the part above B be filled with water, to render the whole air-tight, the piſton A being thruſt down to B, and afterwards raiſed, a vacuum or void ſpace will be left between B and A, into which the air contained in the lower part of the pipe CB, will expand itſelf. The ſpring of this air being thus weakened

weakened by the expanſion, can no longer counterpoiſe the effect of the preſſure of the atmoſphere, and the water will riſe in the tube till the equilibrium is reſtored. By depreſſion of the piſton A, the valve B is ſuffered to cloſe, and a part of the air between the valve and piſton eſcapes through A. After a few ſtrokes, the whole of the included air is extracted, the water riſes through the valve B, and is drawn upwards, and diſcharged by the piſton A. And this operation may be continued at pleaſure. But if the height BC be more than 34 feet, the water will not riſe to the valve; for a column of freſh water of that length being equal to the weight of the atmoſphere, it can be raiſed no higher by that weight. Thus alſo it is, that the mercury in the barometer ſtands but to a certain height; and if a pump finiſhed with the utmoſt exactneſs on the above principle be made to work in mercury, it will not raiſe it beyond that height.

The fire-engine acts by means of the weight and elaſticity of the air. For it is compoſed of two barrels, E and D, (fig. 120.) in each of which a ſolid piſton or plunger

plunger is worked by means of a double lever. Theſe barrels communicate with the water by a pipe not expreſſed in the figure: they alſo communicate with the ſtrong cylinder or veſſel CC, by the pipes L and T. At M and K in the barrels are valves opening upwards, and at L and T are valves which open towards the cylinder. In the figure, the piſton in D being raiſed, the water ruſhes in at D, while that in E being depreſſed, forces its contents into the cylinder through the valve T. At the next ſtroke the barrel E raiſes the water, while the contents of the barrel D are forced into the cylinder: and thus the alternate actions of raiſing and forcing may be continued at pleaſure. Now the water being forced into the cylinder, compreſſes the air contained within, into a ſmall ſpace; which air reacting on the water, drives it in a continual ſtream through the pipe POQR, which may be directed as neceſſity ſhall require.

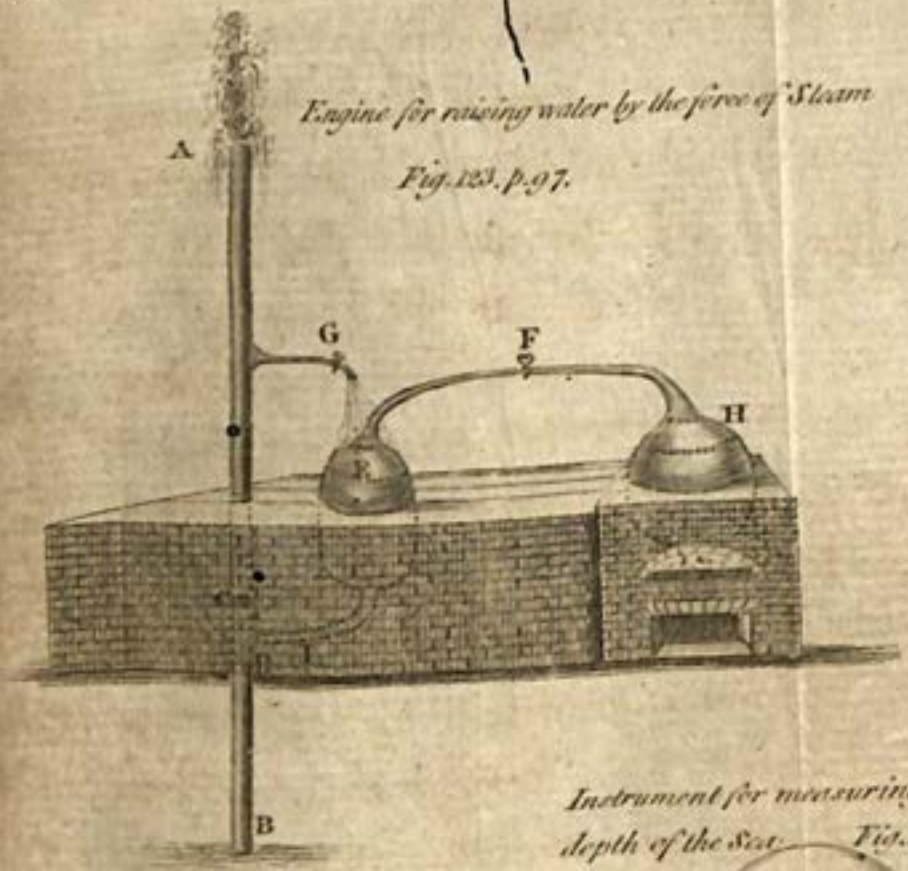
That the force of compreſſed air is very great, appears by many experiments, particularly in the performance of the wind-gun. Fig. 121. repreſents a ſection of this inſtrument.

inſtrument. A K is the barrel, containing a ball at K. This barrel is contained within another larger tube CDRE, and in the intermediate cavity, the air is compreſſed and kept. MN is a cylindrical cavity in the ſtock or butt end of the piece, in which a piſton works for the purpoſe of forcing the air into the before-mentioned cavity. The air is prevented from returning by the ſhut or valve P, which is opened by the air, as it is forced in, but at other times, is kept ſhut by the ſpring of the included air. At L is placed another valve, which, by means of a ſpring is preſſed cloſe on the orifice of the barrel, and prevents the air from eſcaping. To this valve is affixed a wire, which, paſſing through a hole that is rendered air-tight by wet and greaſy leather, appears afterwards at O, in the form of a trigger. When the trigger is drawn back, the valve L opens, and the air ruſhing out, drives the ball with a force that ſeems not much leſs than if it were diſcharged from a muſquet.

A variety of curious and pleaſing fountains may be formed by the help of the properties of the air combined with hydroſtatical principles.

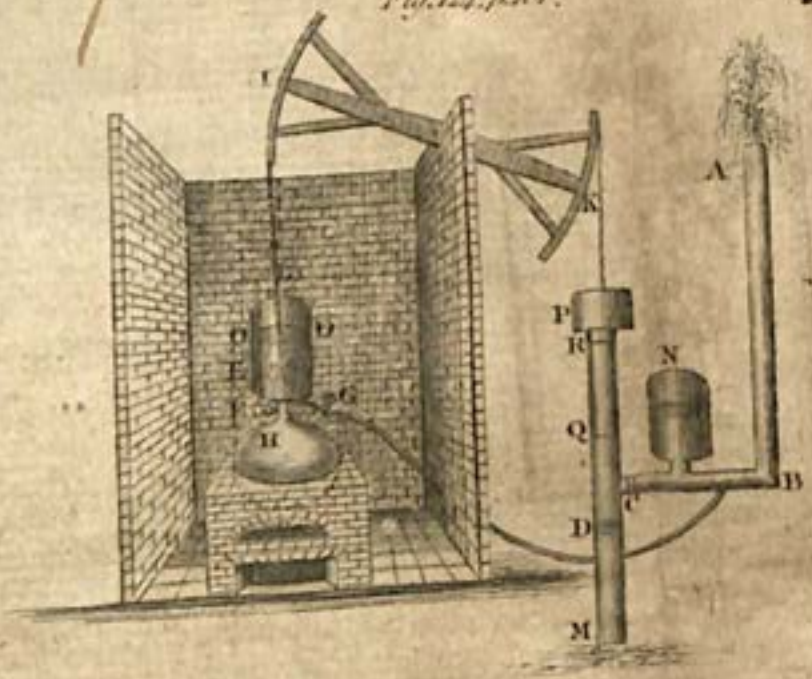
Engine for raising water by the force of Steam

Fig. 123. p. 97.



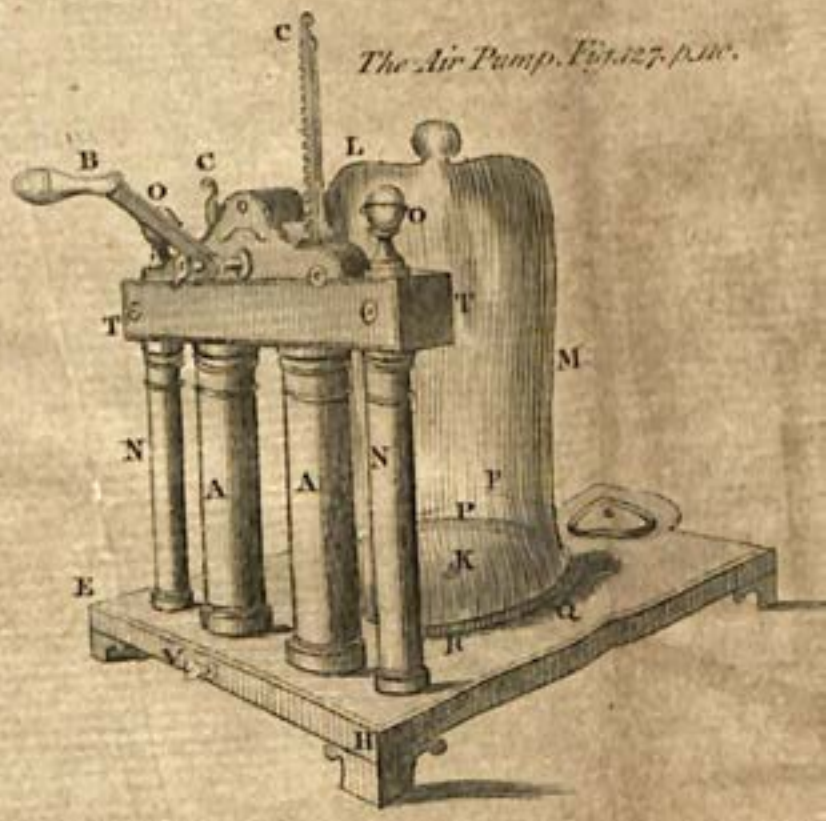
Engine for raising water by the force of Steam

Fig. 124. p. 101.

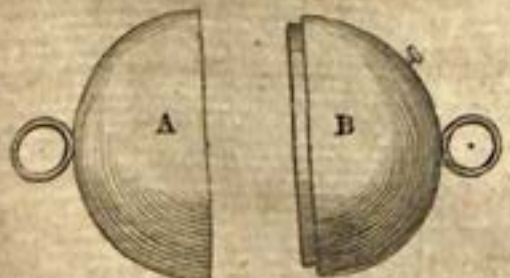


Instrument for measuring the depth of the Sea. Fig. 125. p. 106.

The Air Pump. Fig. 127. p. 110.



Pressure of the Air Fig. 126. p. 117.



principles. The following is the moſt in eſteem. ABCD (fig. 122.) is a copper veſſel, near two-thirds filled with water: at M is ſcrewed in, the tube IG, the junction being made air-tight by means of wet and greaſy leather, and in the upper part of the tube is fixed a ſtop-cock H. The ſtop-cock being opened, a forcing ſyringe is ſcrewed on at I, and a great quantity of air injected, whence the air in the cavity ABFE being very much condenſed, preſſes on the ſurface of the included water. The ſtop-cock being then ſhut, the ſyringe is removed, and an adjutage ſcrewed on in its place; through which, if the ſtop-cock be again opened, the water will ſpout forth with great violence.

In many mechanical engines, where the force of an elaſtic fluid is required, the ſteam of boiling water is made uſe of, by reaſon that it is eaſily obtained, and is prodigiouſly elaſtic.

The firſt engine of which we have any account, for raiſing water by the force of ſteam, was conſtructed about a century ago upon the principle of the figure, (fig. 123.) in which H repreſents a copper boiler placed on a fur-

nace. E is a ſtrong iron veſſel which communicates with the boiler by means of a pipe at top; and with the main pipe AB, by means of a pipe I at bottom. AB is the main pipe immerſed in the water at B. D and C are two fixed valves, both opening upwards, one of which is placed above, and the other below the pipe of communication I. Laſtly, at G is a cock which ſerves occaſionally to wet and cool the veſſel E, by water from the main pipe, and F is a cock in the pipe of communication between the veſſel E and the boiler.

The engine is ſet to work, by filling the copper in part with water, and alſo the upper part of the main pipe above the valve C, the fire in the furnace being lighted at the ſame time. When the water boils ſtrongly, the cock F is opened, the ſteam ruſhes into the veſſel E, and expels the air from thence through the valve C. The veſſel E thus filled, and violently heated by the ſteam, is ſuddenly cooled by the water which falls on it upon turning the cock G, the cock F being ſhut, to prevent any freſh acceſſion of ſteam from the boiler. In conſequence of this, the ſteam

in

in E becoming condenſed, leaves the cavity within almoſt intirely vacuous: the preſſure of the atmoſphere at B, therefore, forces the water through the valve D till the veſſel E is nearly filled. The condenſing cock G is then ſhut, and the ſteam cock F again opened; the ſteam ruſhing into E, expels the water through the valve C as it before did the air. Thus E becomes again filled with hot ſteam, which is again cooled and condenſed by the water from G, the ſupply being cut off by ſhutting F, as in the former operation: the water conſequently ruſhes through D, by the preſſure of the atmoſphere at B, and E is again filled. This water is forced up the main pipe through C, by opening F and ſhutting G, as before. It is eaſy to conceive, that by this alternate opening and ſhutting the cocks, water will be continually raiſed, as long as the boiler continues to ſupply the ſteam.

For the ſake of perſpicuity, the drawing is diveſted of the apparatus by which the two cocks are turned at once, and of the contrivances for filling the copper to the proper quantity. The engines of this con-

ſtruction were uſually made to work with two receivers or ſteam veſſels, one of which received the ſteam, while the other was raiſing water by the condenſation. This inſtrument has been ſince improved, by admitting the end of the condenſing pipe G into the veſſel E, by which means the ſteam is more ſuddenly and effectually condenſed than by water on the outſide of the veſſel.

The advantages of this engine are, that it may be erected in almoſt any ſituation, requires but little room, and is ſubject to very little friction in its parts: its diſadvantages are, that great part of the ſteam is condenſed, and loſes its force upon coming into contact with the water in the veſſel E, and that the heat and elaſticity of the ſteam muſt be increaſed in proportion to the height to which the water is required to be raiſed. On both theſe accounts a large fire is required, and the copper muſt be very ſtrong, when the height to which the water is intended to be raiſed is conſiderable, otherwiſe there is danger of its burſting. The following engine, though in general bulky,

and

and more expenſive in its conſtruction, is leſs chargeable in fuel, as it acts by means of ſteam whoſe denſity is not much greater than that of the common air.

In fig. 124. H repreſents the copper boiler on its furnace. E is a cylindrical veſſel of iron, in which the piſton OO moves up and down; the edges of the piſton being armed with oakum and greaſe, render the whole cavity between the piſton and the bottom of the cylinder air-tight. F is a cock by which ſteam is occaſionally let into the cylinder from the boiler. IK is a lever, attached to the piſton at I, and at K to the piſton of a pump which works on that ſide. PQ is a ſolid piſton which moves in the pipe RM, and which is loaded with a heavy weight at P. ABC is the main pipe into which the water is forced from RM through a valve C opening outwards. N is an air veſſel communicating with the main pipe. D is a valve opening upwards, and at M is the water to be raiſed.

In the drawing, the engine is repreſented in the poſition which it has at the end of a forcing ſtroke, which is likewiſe its poſition

when at reſt. Suppoſe the main pipe ABC to be filled with water, and the water in the copper H to boil ſtrongly. The cock F being then opened, the ſteam ruſhes into the cylinder, and being much lighter than the air, riſes to the top, and expels the air through a valve in the bottom of the cylinder. This being accompliſhed, F is ſhut, and the cock G communicating with the main pipe is opened, which immediately condenſes the ſteam by violently ſpouting cold water againſt the bottom of the piſton. A vacuum being thus obtained, the preſſure of the atmoſphere forces the piſton down to the bottom of the cylinder; the lever IK is moved of courſe, the piſton PQ with its weight is raiſed, and the water aſcends in the pipe MR upon the principle of the common pump. The cock G being now ſhut, and F opened, the ſteam enters the cylinder, and counteracts the preſſure of the atmoſphere on the piſton OO. In conſequence of this, the weight P prevails, and drives down the piſton RQ, which forces the water through the valve C into the main pipe and its air veſſel. The uſe of the air veſſel is to prevent the main pipe

pipe from burſting by the ſudden entrance of the water; for the air at N being elaſtic, gives way in ſome degree to the ſtroke. By opening the cock G and ſhutting F, the ſteam is again condenſed, the preſſure of the atmoſphere again prevails, and thus the work may be continued at pleaſure.

In this drawing likewiſe, the mechaniſm is omitted, by which the cocks are opened and ſhut. This office is performed by a beam and ropes attached to the lever IK; ſo that the attendance required is very little more than is neceſſary to ſupply the boiler with water, and to prevent the fire from going out.

The peculiar advantage of this engine is, that the water may be forced to any height without increaſing the force of the ſteam, which never need be much greater than that of the atmoſphere; and therefore the boiler is very little endangered. The maximum of its power deends upon the area of the piſton OO; for the larger the area, the greater the column of the atmoſphere by which it is preſſed, and conſequently the heavier the weight P may be. If OO be 36 inches in

diameter, it will be preſſed by a column of the atmoſphere equal in weight to a column of mercury of that diameter, and 30 inches in height; that is to ſay, almoſt 7 ton.

But, notwithſtanding the great ſkill and contrivance diſplayed in this engine, it is at preſent almoſt entirely ſuperſeded by one of a much better conſtruction, invented and perfected by Meſſrs. *Watt* and *Bolton*, of *Birmingham*. Thoſe gentlemen ſeem to have carried the art of raiſing water, by means of ſteam, as far as it will go, both with reſpect to the theory and the execution; but as they are yet only beginning to enjoy the fruits of their ingenuity and labour, it might be doing them an injury to publiſh a ſcientific deſcription of their engine. We ſhall therefore content ourſelves with obſerving, that inſtead of depreſſing the piſton OO by means of the weight of the atmoſphere, the ſteam is thrown upon it, the upper part of the cylinder E being cloſed, and the rod L, which is ſmooth and poliſhed, being admitted through a perforation, which is wadded ſo as to be air-tight. The aſcent of the piſton is obtained by letting the ſteam out

of the cylinder into a veſſel at a conſiderable diſtance, where it meets with, and is condenſed by a jet of cold water; while a vacuum is conſtantly maintained in the lower part of the cylinder by the action of an air-pump. The force of ſteam employed in this engine is uſually equal to one atmoſphere and a quarter, and the whole apparatus is regularly worked by the principal lever IK. The advantages of this conſtruction are, that by increaſing the force of the ſteam the power of the engine may be increaſed, without enlarging the diameter of the cylinder; and a leſs expence of ſteam is required on account of the condenſation being performed at a diſtance from the cylinder, which is not therefore cooled by the injection of the cold water. To theſe we may add the peculiar neatneſs and accuracy with which the apparatus is finiſhed, which cannot but greatly contribute to facilitate the working of the engine. On theſe accounts, the expence of fuel is very much leſs than in any which have been hitherto conſtructed.

The elaſticity of the air affords a method of determining the depth of the ſea in places where

where a line cannot be uſed. Fig. 125. is a machine for this purpoſe. A repreſents a large ball of fir or other light wood, varniſhed over, to preſerve it from the effects of the water; B is a hollow glaſs veſſel, whoſe contents in ſea-water is exactly known; ſuppoſe, for inſtance, two pounds: its neck C terminates in a ſmall orifice, and is bent downwards, to prevent the eſcape of the included air, when it is immerſed in water. At E is a ſpring-hook, which, if at liberty, would ſtand in the poſition e, but which is preſſed through a ſlit in the ſtem at the bottom, and kept to its place by hooking on the weight D. The whole inſtrument thus prepared is ſuffered to ſink in the water. And the conſequence is, that as it ſinks, the preſſure of the water continually increaſing, forces its way into the veſſel, and condenſes the air contained within; but when it arrives at the bottom, the weight D ſtriking firſt, is ſtopped, while the reſt of the apparatus proceeds a little onwards, by reaſon of its acquired velocity. The hook E being thus diſengaged from the weight, flies back, and leaves it intirely, by which means the ball A is at liberty to riſe again

to the ſurface. By the quantity of water contained in B at its emergence, it is eaſy to determine the depth to which it has deſcended. For, ſince the denſity of air is as the compreſſing weight, the bulk of the ſame quantity of air under different preſſures, muſt be reciprocally as the weight. And experiment ſhews, that the weight of the atmoſphere is equal to 32 feet of ſea-water: therefore, at the depth of 32 feet, the air included in the veſſel C will ſuſtain the preſſure of two atmoſpheres, and conſequently will be condenſed into half its former ſpace; at 64 feet depth it will ſuſtain the preſſure of three atmoſpheres, and be condenſed into one third of its firſt ſpace, and ſo forth. For example, ſuppoſe an empty ball as above deſcribed, capable of holding two pounds troy of ſea-water, was to deſcend to an unknown depth in the ſea, and at its return was found to contain 1 lb. 11 oz. 18 dwts. of water, it is required to find the depth? Then, As the bulk into which the air was compreſſed, when at the bottom of the ſea, which is expreſſed by 2 dwts. Is to the bulk of the air before immerſion, which is expreſſed by 2

lb.

lb. So is the weight of the atmoſphere, by which the air was compreſſed before immerſion, which is expreſſed by 32 feet of water, To the weight by which the air was compreſſed when at the bottom of the ſea, 3840 feet. From which deduct 32 feet for the preſſure of the atmoſphere, and the remainder, 3808 feet, indicates the depth of the ſea.

This method is ſubject to two objections. The firſt is, that probably the ſpecific gravity of the ſea may be different at different depths, in which caſe the preſſures will not be as the depths: and the other is, that air in very great condenſations does not ſtrictly follow the ratio of the preſſure, but reſiſts in a greater degree. But a careful ſeries of experiments may indicate the allowances which ought to be made on both accounts, and in ſmall depths the inſtrument is ſufficiently accurate on the principle already laid down.

If an empty veſſel, that is to ſay, a veſſel containing air, be immerſed in water with the mouth downwards, the ſpring of the air will prevent the water from filling the veſſel, as may be eaſily ſeen by the help of

a wine-

a wine-glaſs. The diving-bell is conſtructed to ſerve on this principle. It conſiſts of a large veſſel or kind of caſk, ſo loaded with lead as to ſink when empty, with the mouth downwards. In the top is fixed a cock to let out the air, and a ſtrong pane of glaſs to afford light to the divers, who ſit on a circular bench in the inſide. This machine is lowered into the water about twelve feet at a time, and at each pauſe air is ſent down in ſmaller bells to the divers, and by them received into the cavity of the great bell, for the purpoſe of expelling the water, which enters as the preſſure condenſes the included air. After it has arrived at the bottom of of the ſea, they continue by the ſame means to repleniſh the air which becomes foul by breathing, letting the impure air eſcape by the cock in the upper part, as they receive freſh air by the barrels or ſmall bells; by which contrivance they can remain under water as long as they pleaſe. The diving-bell might be applied to good uſe in the pearl fiſhery, and in other affairs of that nature; but has not yet been applied to uſe, except by Dr. *Halley*, and a few other curious and philoſophical gentlemen.

CHAP.

CHAP. VI.

Of the Air-Pump, and its Uſes.

THE moſt uſeful of all philoſophical inſtruments, whoſe actions depend on the properties of the air, is the air-pump. By the help of this machine all that has been ſhewn concerning the weight and elaſticity of the air, is demonſtrated in the moſt ſimple and elegant manner. Its conſtruction is as follows: EFGH (fig 127.) is a ſquare table of wood, AA are too ſtrong barrels or tubes of braſs, which are firmly retained in their poſition by the piece TT, which is preſſed on them by ſcrews OO, which are fixed on the tops of the braſs pillars NN. Theſe barrels communicate with a cavity in the piece D. At the bottom within each barrel is fixed a valve, opening upwards, and in each a piſton works, having a valve likewiſe opening upwards. The piſtons are moved by a cog-wheel in the piece TT, to the axis of which

which the handle B is fixed, and whoſe teeth catch in the racks of the piſtons CC. PQR is a circular braſs-plate, in the center of which appears the orifice K of a concealed pipe, that communicates with the cavity; in the piece D at V is a ſcrew that cloſes the orifice of another pipe, which alſo terminates at K, for the purpoſe of admitting the external air when required. LM is a glaſs-receiver, out of which the air is to be exhauſted. It is placed on the plate PQR, which is firſt covered with a wet ſheep-ſkin, or ſmeared with wax, to prevent the air from inſinuating under the edge of the glaſs. We ſhall not deſcribe the methods and precautions which are uſed to render the whole air-tight, but ſhall proceed to explain the mode of its action.

When the handle B is turned, one of the piſtons is raiſed, and the other depreſſed; in conſequence of which, a void ſpace is left between the raiſed piſton and the lower valve in the correſpondent barrel: the air contained in the receiver LM, communicating with the barrel by the orifice K, immediately raiſes the lower

lower valve by its ſpring, and expands into the void ſpace; and thus a part of the air in the receiver is extracted. The handle then, being turned the contrary way, raiſes the other piſton, and performs the ſame act in its correſpondent barrel; while, in the mean time, the firſt mentioned piſton being depreſſed, the air, by its ſpring, cloſes the lower valve, and, raiſing the valve in the piſton, makes its eſcape. The motion of the handle being again reverſed, the firſt barrel again exhauſts while the ſecond diſcharges the air in its turn: and thus, during the time the pump is worked, one barrel exhauſts the air from the receiver, while the other diſcharges it through the valve in its piſton.

Hence it is evident, that the vacuum in the receiver of the air-pump can never be perfect; that is, the air can never be entirely exhauſted: for it is the ſpring of the air in the receiver that raiſes the valve and forces air into the barrel, and the barrel at each exſuction can only take away a certain part of the remaining air, which is in proportion to the quantity before the ſtroke, as the capacity of the barrel

barrel is to that of the barrel and receiver added into one ſum. Beſides which, there is another circumſtance that impedes the perfection of the vacuum; namely, that there ever will be, in the beſt conſtructed inſtrument, a ſpace between the two valves when the piſton is down, in which a ſmall quantity of air will remain. Now, when the air in the receiver is become ſo rarefied, that its ſpring is only equal to that of the ſmall remaining quantity, when rarefied by raiſing the piſton, it will not raiſe the lower valve, and of courſe the exhauſtion will ceaſe.

But though the vacuum in the receiver of the air-pump is not perfect, yet it is ſufficiently ſo to exhibit moſt of the appearances which would take place in an abſolute void; that is to ſay of air, for the particles of light, and probably other bodies, do exiſt in the vacuum here deſcribed.

There are ſeveral methods of diſcovering the degree of rarefaction of the air within the receiver. The beſt is by means of a bottle in the ſhape of a pear, which is graduated on the outſide to every hundredth part of its contents. This bottle being filled with mer-

cury, a ſmall bubble of air is admitted, and its neck is plunged in a veſſel, likewiſe containing mercury. The preſſure of the air ſuſtains the mercury in the bottle, on the barometer-principle; but when the inſtrument is placed under the receiver, and the preſſure diminiſhed by the exhauſtion, the included bubble is at liberty to expand by the fall of the mercury. And the degree of this expanſion, which correſponds with that of the air in the receiver, is known by the graduations on the bottle. By an inſtrument of this kind it is found, that the air-pumps conſtructed in the beſt manner, as directed by Mr. Smeaton in the Philoſophical Tranſactions for 1752, will rarefy the air more than 1000 times: but the common air-pumps in the ſhops ſeldom rarefy more than 100 times.

We obſerved, that the properties of the air might be very ſimply and elegantly demonſtrated by the aſſiſtance of the air-pump. It will not be amiſs in this place to enumerate ſome of the experiments which are made for that purpoſe.

The weight of the air is proved by exhauſting it out of a bottle, as has already been obſerved.

ſerved. It is alſo ſhewn, that the mercury in the Torricellian tube or barometer is ſuſtained by the preſſure of the air; for, if a barometer be placed under a tall receiver, and the air exhauſted, the mercury will ſubſide gradually as that preſſure is removed. If a ſquare bottle, in whoſe neck is fixed a valve, opening outwards, be placed under the receiver, and the air exhauſted, the bottle will be cruſhed to pieces by the weight of the atmoſphere when the air is permitted to return into the receiver: for the air being prevented from entering the bottle by the valve, the bottle (which, before the exhauſtion, ſuſtained the preſſure of the atmoſphere on its external ſurface, by means of the ſpring of the included air, which acted equally on the internal ſurface) being deprived of its internal air, is incapable of bearing the weight of the atmoſphere which preſſes it on all ſides. If the bottle were round inſtead of ſquare, it would ſuſtain the preſſure, notwithſtanding the exhauſtion, by reaſon of its arched figure, which would prevent its giving way inwards.

The quantity of this preſſure on a given ſurface is equal to the weight of a column of mercury, whoſe baſe is the given ſurface, and whoſe height is the height of the mercury in the barometer, as may be eaſily gathered from the hydroſtatical principles heretofore laid down. To exemplify and prove this by the air-pump, it is uſual to incloſe in the receiver two braſs hemiſpheres, as A and B, (fig. 126.) which ſhut together like a box, and which, at the place of ſhutting, are lined with wetted leather. The air being exhauſted from the receiver eſcapes likewiſe from the cavity of the hemiſpheres, and when it is permitted again to enter the receiver, the hemiſpheres are ſo cloſely preſſed together, that the air cannot enter at the place of junction: conſequently they adhere together, with a force equal to the preſſure of the atmoſphere, which is greater or leſs in proportion to the area of the circle at the place of junction: thus, by the above rule, if the diameter of the circle at which the hemiſpheres are joined be four inches, the force required to ſeparate them, muſt exceed 230 lb. troy.

Since bodies, immerſed in fluids, loſe parts of their weights, which are equal to the weights of maſſes of the fluids reſpectively equal in bulk to the bodies themſelves, it follows that bodies of different ſpecific gravities, which are in equilibrio in the air will not remain ſo in vacuo. For in vacuo each body will re-acquire the weight which they may be ſaid to loſe while in the air, and the body whoſe bulk is greateſt will acquire the greateſt weight. Thus, if a piece of cork be in equilibrio with a piece of lead, when weighed by fine ſcales in the air, the cork will preponderate in vacuo; the removal of the air adding proportionally more to its weight, as its bulk exceeds that of the lead.

The ſpring of the air may likewiſe be ſhewn, in various manners, by the aſſiſtance of the air-pump. If a ſmall tube be inſerted through the cork of a bottle, half full of mercury, ſo that the communication between the air included in the upper part of the bottle and the external air be entirely cut off, the end of the tube being immerſed in the mercury; and this apparatus be placed

under the receiver and the air exhauſted: then the ſpring of the included air, preſſing on the ſurface of the mercury, will force it into the tube, and ſuſtain it at the ſame height nearly as its ſtands in the barometer; the ſpring of the air being equal to its weight, and conſequently producing an equal effect: but on account of the imperfection of the vacuum, the ſpring of the ſmall remaining quantity of the air in the receiver prevents the mercury from riſing exactly as high as it does in the barometer.

If a half blown bladder be placed in the receiver, the included air will expand, as the exhauſtion proceeds, and will blow it up even to burſting. And if this bladder be incloſed in a box, whoſe cover is loaded with weights ſomewhat leſs than equal to that of the atmoſphere, the expanſion will raiſe the cover and ſuſtain the weights. Thus if the bladder be incloſed in a box of 6 inches diameter, it will raiſe the cover, though loaded with upwards of 500 lb. troy, as may be eaſily gathered from the conſideration, that the ſpring of the air is equal

to

to its weight; which weight may be found by the rules eſtabliſhed above.

The ſpring of the air, which is included in the larger pores or veſſels of bodies, is the foundation of a number of pleaſing and inſtructive experiments. Thus it is found, that wood is ſpecifically lighter than water, only by reaſon of the ſpring of the air included in its veſſels, which prevents the water from entering: for when this air is extracted, and the water, by the admiſſion of the external air into the receiver, is impelled into the veſſels of the wood, it is always found to ſink to the bottom.

The refractive power of the air is alſo ſhewn by the air-pump. For if the air be exhauſted out of a priſmatic glaſs veſſel, the rays of light will not paſs ſtrait through its ſides, but in entering the vacuum, are deflected from the perpendicular, and at their emergence into the air, are deflected towards the perpendicular, according to the eſtabliſhed laws of optics. The proportions of the ſines of the angles of incidence and refraction, out of the vacuum into the air, are by this means found to be as 100056 to 100000,

which is nearly the ſame ratio as that which is deduced from the refractions of the heavenly bodies.

It is likewiſe proved by the air-pump, that the air is the medium of ſound. A bell or ſmall alarm clock, being rung in the exhauſted receiver, gives no ſound, but if the air be admitted, the ſound gradually becomes louder and louder, till the air in the receiver be of the ſame denſity with that of the atmoſphere, at which time the ſound is no otherwiſe weakened, than on account of the receiver by which the bell is covered.

We have frequently mentioned the reſiſtance of the air. The quantity of this reſiſtance is very conſiderable, and may be diſcovered by calculations grounded on the principles laid down at Ch. 4. Sect. 3. this book. Were it not for this reſiſtance, all bodies falling together from the ſame height, would arrive at the ground in the ſame time. This is ſhewn in the air-pump; for if a guinea and a feather be let fall together from the top of a tall exhauſted receiver, they both arrive at the bottom at the ſame inſtant.

Among

Among the very numerous instances of the uſefulneſs of this inſtrument, we ſhall mention but two more; namely, the diſcovery of the abſolute neceſſity of air for the preſervation of life in moſt animals, and for the production and continuance of flame. Moſt animals, when included in the exhauſted receiver, are obſerved to die in about five minutes, though the time is various in different ſpecies, and they recover again for the moſt part, if the air be again admitted without being withheld too long. A lighted candle being placed under the receiver, is extinguiſhed at the beginning of the rarefaction, and the ſmoke hovers about the top of the receiver; but when the air is ſtill more rarified, it ſubſides to the bottom, as being ſpecifically heavier. Gun-powder may be lighted in vacuo, by means of a hot iron or a burning-glaſs, but it explodes grain by grain, in a different manner from what it does in the open air; and phoſphorus ſhines even more in vacuo than in the open air.

BOOK III.

SECT. I.

Of Chemiſtry.

THE phenomena which are explained in the foregoing part of this work, are chiefly ſuch as depend on a very few firſt principles, and are in general eaſily accounted for, by a ſynthetical reference to them. But that part of natural philoſophy which remains to be conſidered, is ſtill in the proceſs of analyzation. It is difficult to abridge a ſcience which is almoſt purely experimental, and which therefore conſiſts of many facts and little theory; ſince every attempt at brevity muſt be attended with ſome omiſſion, perhaps of importance. In this department of phyſics, error ſurrounds us on all ſides.

When

When we attend to the ſpecific properties of bodies, we continually find ourſelves at a loſs: and it is at preſent quite uncertain, whether figure, denſity, progreſſion, vibration, and other mechanical affections, which we obſerve in aggregate maſſes, be of any great conſequence to the actions which take place among the particles. We ſhall therefore proceed to treat of chemiſtry with that diffidence and caution which the intricacy of the ſubject demands.

CHAP.

CHAP. I.

Of Chemiſtry, and the Methods of decompounding Bodies.

CHEMISTRY is a ſcience which relates to thoſe properties of bodies which ſeem to be ſpecific, and do not apparently depend on any organization or evidently mechanical operation of their parts.

The obvious method of examining any compound ſubject is to attend ſeparately to the parts of which it is compoſed. This method is adopted by natural philoſophers in their enquiries into the properties of bodies.

The parts of ſome bodies may be mechanically ſeparated from each other by pulverizing and immerſing the powder in a fluid, whoſe ſpecific gravity is intermediate between that of the ſeveral particles; in which caſe they will be ſeparated by the ſubſidence of the heavier: thus, clay and ſand may be ſeparated by means of water; the ſand immediately ſubſides, and the clay and water may be decanted

canted off. Powders may alſo be ſeparated by filtration or ſtraining, the larger particles remaining on the filter, and the ſmaller paſſing through. But this cannot with propriety be called decompoſition, and is totally inſufficient for chemical purpoſes.

If an uniform compounded body be ſuppoſed to be divided into the ſmalleſt parts which are poſſible, ſo that thoſe parts may be of the ſame nature as the maſs itſelf, the body is ſaid to be mechanically divided, and theſe ſmalleſt parts are called integrant parts; but if the diviſion be carried farther, the body is ſaid to be decompounded, and the parts are called conſtituent parts or principles. Thus for example, ſulphur is found to conſiſt of an acid united with phlogiſton, or the principle of inflammability: if this ſulphur be imagined to be gradually reduced to the ſmalleſt particles, the diviſion is ſaid to be mechanical as long as the particles continue to be ſulphur; when the diviſion is carried ſo far that it cannot be continued without ſeparating the particles of acid from the phlogiſton, thoſe ſmalleſt particles of ſulphur are called its integrant parts;

but

but when, by continuing the diviſion, the particles ceaſe to be ſimilar, and are ſeparated into acid and phlogiſton, the body is ſaid to be decompounded, and the acid and phlogiſton are ſaid to be the conſtituent parts or principles of the compound ſulphur.

Numberleſs experiments prove, that the attraction of coheſion by which bodies are united into maſſes, is ſubject to very conſiderable mutations. The varying hardneſs, elaſticity, &c. of different bodies, prove that its force is not uniform after the rate of the maſs, like gravity. It is found to be ſtronger or weaker between different bodies in like circumſtances; and the adheſion of the parts of the ſame body is greater or leſs, accordingly as the temperature of the body with reſpect to heat is leſs or greater.

The attraction, by which one body unites with another and forms a compound, is called its affinity with that body. Theſe affinities are likewiſe termed elective attractions, on account of their variations of force with reſpect to different bodies: thus the affinity or elective attraction of water

to

to ſpirit of wine is greater than to nitre; for, if ſpirit of wine be poured on a ſtrong ſolution of nitre in water, the water unites with the ſpirit, quitting the nitre, which immediately falls to the bottom in its proper form.

The quantity of the attraction of cohesion in the parts of the ſame body is ſuſceptible of great variety, according to the temperature with reſpect to heat. If the heat exceed not a certain degree, the body is ſolid; if the heat be greater, the body is fluid or melted; a ſtill greater degree of heat ſeems entirely to deſtroy the attraction, which is then turned into repulſion, and the particles conſequently recede from each other, and the body puts on the form of an elaſtic fluid or vapor. The limits, at which theſe changes happen, differ exceedingly in various bodies. Some bodies, as quickſilver, require an extreme degree of cold to become ſolid; others, as air, continue elaſtic in every temperature we can obtain on earth; and, on the contrary, there are bodies, for inſtance, the calx of tin, which will not melt without the greateſt heat.

heat. It is probable, that there are no two bodies which agree in theſe reſpects.

Thoſe bodies which endure the utmoſt violence of heat without being converted into vapor, or enduring any change except in figure, are called fixed: thoſe which eaſily riſe in the form of vapor, are called volatile. Theſe terms are merely relative. There is great reaſon to think, that all bodies might be converted into vapor by a heat ſufficiently great.

Bodies are decompounded either by altering their temperature, or by the elective attraction of ſome other body. Thus, if there be two bodies, ſalt and water, for example, whoſe fixity is very different, a ſufficient heat will deſtroy the attraction between them; and the water, being more volatile, will fly off in vapor. On the contrary, a great degree of cold will cauſe the ſalt to ſeparate in part from the water, in its ſolid form, probably becauſe the mutual attraction of the parts of the ſalt is more augmented by cold, than the attraction which ſubſiſts between the ſalt and the water.

water. The ſecond method of decompounding, is, by preſenting a body which has a ſtronger affinity with one of the principles of the body to be decompounded than its remaining principles have. Common ſalt, for example, conſiſts of two principles, which are known by the name of marine acid and mineral alkali. If the acid of vitriol be added, it unites with the mineral alkali, by means of its ſtronger affinity, and the marine acid flies off in the form of vapor.

It is evident, from all the phenomena, that the attraction of coheſion is greater, in like circumſtances, the nearer bodies approach to each other. For this reaſon, the parts of a ſolid body muſt attract each other with more force than they can be attracted by another ſolid body which cannot be brought into any perfect or extenſive contact with them. Cold therefore, by rendering bodies ſolid, prevents the elective attractions from appearing in any conſiderable degree: and on the contrary, the greater the degree of heat the more perfectly

in general do the affinities exert themſelves; for fluid bodies or vapors may permeate and mix with each other in every poſſible manner.

CHAP. II.

Of Heat; and the Manner of performing chemical Operations.

SINCE heat is ſo univerſal an agent in all chemical proceſſes, it will be neceſſary to enquire into its properties before we proceed to particulars.

Heat then is that ſtate in which bodies are, when they convey a peculiar ſenſation to the organ of feeling, which is vulgarly known by the ſame term. The cauſe of that ſtate is alſo frequently denoted by the ſame word; but we propoſe to confine ourſelves to this ſingle acceptation.

This definition of heat is relative to the ſenſe of touch, and, as that ſenſe varies in its notices, according to the temperature of the human body, it is by no means accurate

curate enough for philoſophical purpoſes. Underground cellars, which appear cool in ſummer, are ſenſibly warm in winter; but the difference conſiſts only in the relative heat or cold of the body of the obſerver with reſpect to the air in the cellar. Water which appears warm to one hand may ſeem cold to the other, if the hands be not equally warm; and in the autumn, when the winter is juſt beginning to approach, numbers think the weather exceedingly cold, while the perceptions of others are very little affected. Theſe and other ſimilar circumſtances indicate the neceſſity of attending to other appearances which accompany the ſtate of heat, and are leſs equivocal.

In a more enlarged and uſeful ſenſe, it may therefore be proper to ſay, that heat is a ſtate or temperature, in which the dimenſions of uniform bodies are augmented; and the greater the augmentation the greater the heat is ſaid to be.

But in what does this ſtate conſiſt? The increaſe of bulk is only a collateral circumſtance. Does heat conſiſt of particles of aſtoniſhing ſubtilty, which permeate the

denſeſt bodies without difficulty,——which, being endued with a peculiar and rapid motion, are in themſelves eſſentially fluid, and the cauſe of agitation and fluidity in other bodies?—or, is it no more than a certain motion or vibration impreſſed on the parts of bodies, which prevents contact and coheſion in proportion as it is more or leſs violent; and which, if encreaſed beyond a certain degree, throws the particles out of the limit of attraction, and cauſes repulſion to take place? This ſubject is ſurrounded with difficulties.

It is uſual to judge of the quantity of heat by the increments of the bulks of bodies. Thus, if the quickſilver in the tube of a thermometer be raiſed five degrees beyond a certain ſtandard, by being immerſed in a fluid, and after that, be immerſed in another fluid, and raiſed by that means ten degrees, we ſay, the quantity of heat in the latter is twice as great as in the former fluid.

But this method of reaſoning is erroneous: for whatever heat may be, the thermometer can only ſhew when the quantities in two bodies are equal, or indicate that one of the bodies is hotter, without fixing the ratio of the

the quantities of heat. The expanſion of bodies very probably follows ſome direct ratio of the quantity of heat; but whether that ratio be ſimply as the increments of the bulks, or whether it follow any other law, has not yet been determined.

Heat ſeems to be a ſtate of force on bodies. The action of the Sun cauſes that heat which prevents all bodies from congealing into abſolute rigidity and inaction. And it is probable that there is no body on earth entirely deprived of heat. The means by which heat is produced, or to ſpeak more properly, augmented, are firſt, the action of the rays of light, ſecondly, the colliſion of bodies, and thirdly, the mutual concurrence of two bodies, whoſe affinities to each other are very ſtrong.

What can be more natural than to ſuppoſe, that the parts of bodies are put into a vibrating motion by the ſwift and repeated ſtrokes of the particles of light?—Can the colliſion of flint and ſteel be performed without a very violent agitation at the place of contact?—And is not there the higheſt probability, when the particles of two fluids,

ſor example, water and the vitriolic acid, ruſh together by means of a ſtrong affinity, that a great inteſtine motion muſt take place before the parts are reſpectively ſo ſituated, as that their mutual tendency ſhall be ſatisfied as much as circumſtances admit? It is ſcarcely hypothetical, then, to affirm that heat is always accompanied with an inteſtine motion of the parts of bodies. And if this inteſtine motion be of itſelf ſufficient to account for the phenomena of heat, why ſhould we multiply cauſes, and call in the aſſiſtance of a fluid to which we muſt give a number of ſurpriſing properties, namely, continual activity, eſſential fluidity, and a ſubtilty ſo amazing, as to enable it repeatedly, without a poſſibility of deflection, to paſs through the denſeſt bodies, without leaving a trace of its having been there?

It is true that obſcurity will always attend ſpeaking concerning a ſubject which is very little known. We do not know the nature of this motion, nor how it is propagated, but its exiſtence can hardly be doubted; and when we look without prejudice into the regions

regions of conjecture, it appears at leaſt as eaſy to conceive, that bodies may be conſtructed to vibrate more or leſs readily, as that they ſhould have greater or leſs capacities for imbibing a fluid called heat.

On the other hand, it muſt be confeſſed, that mere motion or its abſence ſeems inſufficient to account for the cold produced during the combination of water with ſal ammoniac, or that very intenſe cold which is obtained by the evaporation of either.

If a number of bodies poſſeſſed of various degrees of heat be put into contact, the heat is communicated from the one to the other, ſo that they will all, at length arrive at the ſame temperature. On this account bodies heated beyond the temperature of the circumambient air and veſſel in which they are contained, muſt return to that temperature more quickly than they would otherwiſe do.

All fixed bodies, if heated beyond a certain degree, emit light and ſhine: and if certain bodies, which contain a principle called phlogiſton, be made very hot, with acceſs of pure air, the heat will increaſe, and be commu-

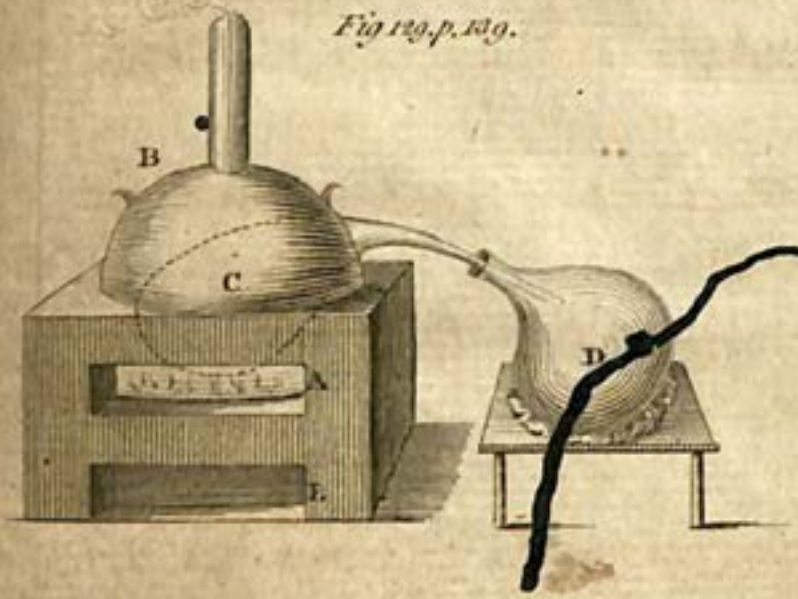
nicated without diminution, from one body to another, till the bodies are in a very conſiderable degree decompounded, and the phlogiſton diſſipated. This remarkable phenomenon is called combuſtion or burning.

Does not this appearance greatly depend on the affinity between pure air and phlogiſton? A certain degree of heat diminiſhes the attraction between the phlogiſton and the other principles of the body which contains it, and allows the affinity between air and phlogiſton to take place. They ruſh together and exceedingly increaſe the heat, which muſt continue without diminution, as long as the body continues to afford phlogiſton to combine with the air.

The moſt convenient practical method of producing heat in a given body, is by applying it to other bodies, which are in the act of combuſtion. A much greater degree of heat is procured by converging the Sun's rays by a lens or mirror, but the focus is not extenſive enough to be generally uſeful. The heat produced by means of a flint and ſteel, ſeems to be even greater than

that

Reverberatory Furnace
Fig 129.p.139.



Air melting Furnace
Fig.127.p.138.

Alembic Fig.132.p.140.

Alembic or Still. Fig.133.p.150.

Crucible Fig.128.p.138.

Saturation Fig.131.p.145.

Retort Fig.130.p.140.

that which is generally obtained by a burning-glaſs; for the ſparks or particles of flint which are ſtruck off, appear, when examined by the microſcope, to have been completely vitrified, or reduced to glaſs. It may be readily imagined, that the heat, which, in an inſtant, produces this effect on a ſubſtance ſo refractory as flint, muſt be extremely violent.

Combuſtion depending ſo much on the acceſs of air, it follows, that it muſt be more violent in proportion as the air is more plentifully ſupplied. Hence the uſe of the bellows. But in moſt proceſſes in which fire is employed, it is inconvenient to uſe them, and yet a conſtant ſupply of air is neceſſary. For this purpoſe furnaces have been invented of a great variety of forms and magnitudes, according to the intention they were meant to ſerve. It will be ſufficient to give a general idea without entering into a detail on this ſubject; we ſhall therefore deſcribe only a few of the inſtruments by which bodies are expoſed to the action of heat.

Fig.

Fig. 127. is a vertical ſection of the air melting-furnace. A is the door of the aſh-hole, B a grate at the bottom of the fire-place, which is covered at top with a flat ſtone, F. The communication between the chimney E and the fire-place is ſideways at G; and the manner of its performance may be thus explained. The ſtone F being taken off, a crucible (fig. 128.) containing the matter intended to be melted or burnt, is placed on a ſtand at C, and covered with a tile; it is then ſurrounded and covered with burning charcoal, and the ſtone replaced at F. The heated charcoal rarefies the air contained in the fire-place, which becoming ſpecifically lighter than the external air, muſt, upon the principles of hydroſtatics, aſcend up the chimney. A conſtant current of air therefore ruſhes through the aſh-hole, and urges the fire; and this current will be more or leſs ſwift, the longer the column of rarefied air. If the cover be taken off at F, the air will make its eſcape almoſt immediately after paſſing through the fire, and becoming quickly cool, by the contact of the external

external air, the current will not be very rapid; but if on the contrary F be covered, the heated air will aſcend through the long chimney E, without being much condenſed. It will therefore be expoſed a much longer time to the action of the air which preſſes in at *B*, and will continually increaſe its velocity till it iſſues with great rapidity at H. The current of air by which the fire is excited, will conſequently be much more violent in this latter caſe than in the former.

In the opening or flue G, in the figure is placed a flat crucible D, ſomewhat reſembling a ſalt-ſellar. It is called a cupel, and is uſed by aſſayers for purifying gold or ſilver. Thoſe metals are expoſed together with lead to the action of the flame which paſſes through G: the heat vitrifies the lead, which combines with the baſer metals, and ſoaking into the cupel, leaves the gold or ſilver in a ſtate of great purity.

Fig. 129. is a perſpective view of the reverberatory furnace. A is the fire-place, E the aſh-hole, and B the dome by which the flames are reverberated or reflected on the

the upper part of the veſſel C, denoted by the dotted curve line. The veſſel C, of which fig. 130. is a drawing, is called a retort, and is uſually made of glaſs or clay, according to the ſtrength of heat it is intended to endure. D is the receiver, into which the noſe of the retort is fixed by means of clay: this is alſo of glaſs, and has a ſmall perforation in the upper part of its neck, to prevent its burſting by means of the rarefied vapors. The method of uſing this apparatus is obvious. The ſubject to be analyzed is put into the retort, and expoſed to the fire; the volatile parts riſe in the form of vapor, and paſs over into the receiver, which being cold, condenſes the greater part of them into a liquid. But if the body be of ſuch a nature, that its volatile principles adhere too ſtrongly to its fixed part, the volatile parts muſt be detached by means of an additional ſubſtance, whoſe elective attraction towards the fixed part is greater. This has already been obſerved in the laſt chapter, and the inſtance there adduced will again ſerve our purpoſe of explanation. Pure common

ſalt,

ſalt, which conſiſts of the fixed mineral alkali, and an acid of conſiderable volatility, called the marine acid, will endure a very ſtrong fire without being decompounded, but if the acid of vitriol be added, its ſtronger affinity with the mineral alkali will form a new compound, called Glauber's ſalt; and the marine acid being detached, will eaſily ariſe in fumes and become condenſed into a fluid in the receiver. This proceſs is called diſtillation.

If a body being expoſed to the action of fire, riſe either entirely or in part, and the volatile fumes becoming condenſed into a dry powder adhere to contiguous bodies; as for example, a part of burning fuel adheres to the chimney in form of ſoot: the proceſs is called ſublimation, and the powder is called flowers. Thus flowers of Benjamin, flowers of antimony, &c. are parts of thoſe ſubſtances which are raiſed by ſublimation.

It may ſeem ſtrange at firſt conſideration, that heat, which diminiſhes the attractions of the parts of bodies, ſhould cauſe ſeveral affinities to exert themſelves

which

which were not apparent in a colder ſtate: but not to mention the reaſon alledged at the concluſion of the laſt chapter, it ſeems natural to imagine, that the weaker affinities are deſtroyed by leſs heat than the ſtronger. Thus the affinity between the marine acid and the mineral alkali being deſtroyed by a degree of heat which is inſufficient to deſtroy the affinity between the acid of vitriol and mineral alkali, this laſt affinity muſt exert itſelf much more evidently than before.

It is not probable that bodies have any chemical action on each other, except when one or more of them is either in a fluid or vaporous ſtate. When a ſolid body is combined with a fluid, it is ſaid to be held in ſolution, or diſſolved in the fluid. In this ſtate of ſolution bodies diffuſed in fluids are actuated according to their affinities with each other, and with the fluid which ſuſtains them. The method of analyzing or compounding by means of a fluid whoſe temperature does not conſiderably differ from that of the atmoſphere, is called the moiſt way, in contradiſtinction to the other method, in which a ſtrong heat is uſed, and which is termed

termed the dry way. The intermediate fluid by whoſe means the affinities are exhibited is called a medium; but when its power of diſſolving is only adverted to, it is called a menſtruum.

As the effects of the mutual attraction between two loadſtones are not ſeen while the loadſtones lie on a table, but become evident as ſoon as they are made to float at liberty on the ſurface of water; ſo the affinities between the parts of two bodies, which are held in ſolution, and move readily in all directions in a menſtruum, may become manifeſt upon a ſimilar principle.

A menſtruum at a given temperature will hold in ſolution no more than a limited quantity of any ſubſtance. This quantity depends on the temperature of the menſtruum, and the affinity which obtains between it and the body to be diſſolved. A menſtruum is ſaid to be ſaturated with a body when it has diſſolved as much as it can ſuſtain; and, perhaps univerſally, a ſaturated menſtruum will not diſſolve any additional quantity of the matter it is ſaturated with. An increaſe of heat in general cauſes a menſtruum

ſtruum to diſſolve and ſuſtain more than it otherwiſe would. This ſeems to contradict the general poſition, that heat diminiſhes the attractions between bodies; but if we advert more minutely to the circumſtances of the fact, this concluſion will not appear to be well founded. Let us ſuppoſe, for an inſtance, that ſalt is the ſubſtance with which it is propoſed that water ſhall be ſaturated. It is evident, that if the attraction between the particles of the ſalt reſpectively, were ſtronger than that which obtains between them and the particles of water, the ſalt would retain its ſolid form; that is to ſay, it would not be diſſolved. But it is diſſolved; and therefore the affinity between the water and ſalt is the ſtronger: conſequently the ſalt muſt be diſunited or diſſolved by a force which is the difference between theſe two attractions: and ſince heat, as has already been obſerved, deſtroys a weaker ſooner than a ſtronger affinity, the proportion of the ſtronger to the weaker muſt continually increaſe as the latter approaches to deſtruction. The effects muſt likewiſe increaſe, from whence it will happen, that the heated menſtruum will more readily

readily diſſolve, and ſuſtain in greater quantity, than when cold.

It is manifeſt that the attractions on which chemical appearances depend, muſt diminiſh while the diſtance of the particles increaſes; for, otherwiſe we ſhould perceive their effects between remote bodies of ſenſible magnitude. The phenomenon of ſaturation may probably depend on this property. Let A (fig. 131.) repreſent a particle of water, and B, C, D, E, F, G, particles of ſalt adhering to, and ſurrounding it. The particle H, therefore, being of neceſſity prevented from coming within a certain diſtance of A, will be but weakly attracted. If the attraction of A on H in this ſituation, be inſufficient to detach it from the maſs I, K, L, M, &c. the particle A may be ſaid to be ſaturated.

But if inſtead of H, a particle of entirely another nature be preſented, with which A has a greater affinity than with B, C, D, E, &c. it may be attracted ſo as to become attached to A without removing thoſe other particles: A being ſaturated with particles of one kind, may therefore notwithſtanding hold others of a different kind in ſolution. Or, if

this laſt affinity be ſuppoſed much greater, the particle may force itſelf between C and D, and by removing one or more of the contiguous particles out of the ſphere of attraction, cauſe it to fall to the bottom of the fluid. And ſo of other particles.

It may be neceſſary to remind the learner, that theſe kind of ſpeculations which relate to the particles of bodies, are in a great meaſure conjectural, and are to be made with prudence and caution. A perſon of a lively imagination may eaſily acquire a facility at making them, and by that means indulge a paſſion for hypothetical theory, which will ſoon deprive him of that ſceptical and cool ſpirit of enquiry which is the firſt requiſite in a philoſopher.

When a body of ſufficient magnitude is immerſed in a menſtruum, already ſaturated with ſome other body with which the menſtruum has a leſs affinity than with the body laſt immerſed, it will let go the firſt body, or ſome of its principles, and diſſolve the other. The body, which thus falls to the bottom in the form of powder, is ſaid to be precipitated, and the powder, if it differ from the

the body firſt diſſolved, is called a precipitate. For example; if copper be immerſed in the acid of nitre, previouſly ſaturated with ſilver, the copper is diſſolved, and the ſilver is precipitated in its natural ſtate, but in powder. But if inſtead of copper an alkaline ſalt be immerſed, the ſilver is precipitated in the form of a white powder called precipitate of ſilver: in this latter caſe the ſilver leaves a minute proportion of one of its principles in the acid.

Organiſed bodies, that is to ſay, vegetable and animal ſubſtances, conſiſt of a maſs of various compounded fluids contained in certain veſſels. Theſe bodies are conſerved during life, by means very little known to us; but when the vital motion ceaſes, the fluids change, the ſolids are deſtroyed and in a great meaſure diſſolved, decompoſitions enſue, and a variety of new combinations take place. The heat of the atmoſphere is commonly ſufficient to effect this change, which is denoted by the general term fermentation.

Fermentation taking place only in very compounded bodies, is by no means well underſtood: it is uſually diſtinguiſhed into

three different ſtages; namely, firſt, the ſpirituous or vinous fermentation, in which a great quantity of noxious or fixable air is detached from the maſs, and a very volatile and inflammable ſubſtance, called ſpirit, is produced, which is eaſily ſeparated by diſtillation. Secondly; the acetous fermentation, by which the maſs is rendered ſour, and vinegar is produced. And thirdly; the putrefactive fermentation, in which a large quantity of pungent volatile alkaline ſalt is produced. Theſe ſtages always ſucceed each other in the above order. Bodies ſuſceptible of the vinous may afterwards undergo the acetous, and laſtly, the putrefactive fermentation; but there is no poſſibility of inverting the order. Bodies which are in the ſtate of the acid fermentation, though they may not have undergone the vinous fermentation, are only capable of proceeding to the putrefactive fermentation; and thoſe which directly acquire the putrefactive fermentation are incapable of either of the others.

The moſt volatile of all ſubſtances, permanently elaſtic vapor, or air excepted, are thoſe which are obtained by fermentation.

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The reverberatory furnace is calculated for extricating the volatile parts of ſuch ſubſtances as require a great heat for that purpoſe. But for obtaining the volatile products of fermented bodies, the form of the apparatus is conſiderably varied. Fig. 132. is an alembic or ſtill. A denotes the body or cucurbit, placed on a furnace, and the dotted lines at B repreſent the head which is environed by a veſſel called the refrigeratory or cooler. The head is contracted into a beak, noſe or ſpout, on one ſide, which paſſes through a hole in the refrigeratory, and is inſerted in the neck of the receiver C. This apparatus is in general made of copper, except the receiver C, which is of glaſs. On the whole, it differs from the reverberatory furnace and its veſſels in being adapted to raiſe and condenſe none but very volatile fumes. For this purpoſe the fire is leſs, and the neck of the cucurbit is longer, and terminates in a head which is kept conſtantly cool by means of water poured into the refrigeratory, and frequently changed. But the alembic of this form is not much in uſe at preſent; the following being more convenient.

A (fig. 133) is the body of the ſtill, B its head, D the worm-tub, and C the receiving-veſſel. The ſtill-head terminates in a pipe, which is bent into the worm-tub in a ſpiral coil, called the worm, as may be ſeen by the dotted lines, and to the lower end of the worm is affixed a cock E. The rationale of this is obvious; for the worm-tub being filled with water, the worm is kept conſtantly cool; the vapors therefore which paſs over from the ſtill are condenſed in their courſe through the ſpiral tube, and are diſcharged in a fluid form by the cock E into the veſſel C. This is the ſtill in uſe by the diſtillers of malt ſpirits. A certain quantity of the extract of malt, which has undergone the vinous fermentation, and is called waſh, is put into the ſtill, from which, by a moderate heat they obtain a weak ſpirit, called low wines, on account of its being combined with much water.

It very often happens, that when two ſubſtances are combined together, the compound partakes of the properties of both: Thus, if volatile matters, which enter into a compound be urged by a quick heat, they will in many caſes carry up ſubſtances, which if alone

would

would not have been raiſed at that temperature. Theſe matters may be ſeparated by a more accurate management of the heat in a ſecond diſtillation. In the preſent inſtance, for example, the ſpirits may be raiſed from low wines by a heat which is not ſufficient to volatilize the water. This proceſs is called rectification, when we ſpeak of the volatile body, but when the fixed body is alluded to, it is called concentration. Ardent and volatile ſpirits being deprived of part of their ſuperabundant water, are ſaid to be rectified; but the acid of vitriol, which is ſo fixed as to be almoſt capable of ignition, is ſaid to be concentrated when a great part of its ſuperabundant water is driven off by heat. The term concentration is alſo applied to that ſeparation of water, from ſome liquids, which is effected by freezing. The ice of vinegar expoſed to freeze is almoſt pure water: this being ſeparated, the remaining vinegar is much ſtronger, and is ſaid to be concentrated. It is affirmed that ſpirituous liquors, as wine, or even beer, may be concentrated by the ſame method.

CHAP. III.

Of chemical Elements; or the claſſing of thoſe Bodies which are leſs compounded than all others.

IN the decompoſition of bodies, the principles or conſtituent parts are by no means ſo various as might be imagined. In fact, the analyſis of all ſubſtances, however different, affords principles ſo exceedingly ſimilar, that chemiſts have been ready to conclude that all bodies are compoſed out of a very few elements, and that the ſenſible differences ariſe only from the proportions of each that obtain in the ſeveral combinations. This opinion has the higheſt probability in its favour, but from the nature of things it is impoſſible for us to be ever aſſured that we are arrived at the elements or firſt principles of bodies. This is a theme on which many reſpectable philoſophers have indulged a paſſion for theoretical conjecture, perhaps too much.

Since that ſeparation of the principles of bodies, in which the chemical analyſis conſiſts, can only be effected by means of the elective

elective attractions, or by heat, it is evident that inſtances muſt occur in which we ſhall be unable to obtain it. For example. Suppoſe two principles of equal fixity, or ſo fixed as to endure without alteration the ſtrongeſt heat we can produce, be combined together by an elective attraction, which in each is ſtronger than its elective attraction to any other body, how are theſe principles to be ſeparated? If they be expoſed to heat they will either riſe together unaltered, or both remain fixed: and if any third body in nature be added, no decompoſition can take place; for, by the condition, the two combined principles attract each other more ſtrongly than they do any other body. Here it may, on the contrary, be obſerved, that we may come at the knowledge of the elements by compoſition; for if any two bodies when combined ſhall produce a compound altogether ſimilar to the body under examination, we may from thence infer, that it is compoſed of the ſame principles: but, in anſwer, it muſt be noticed, that the exiſtence of ſuch uncombined principles being a circumſtance totally unconnected with, and independent of the principal fact, and

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the making the experiment being in a very great meaſure caſual, we muſt in by far the moſt part of ſuch inſtances be ſubject to uncertainty: and that more particularly, becauſe the method of compoſition ſuppoſes a ſimplicity in the principles made uſe of, which can never be proved, ſince the method of analyſis has been ſhewn to be inſufficient for that purpoſe.

Without entering therefore into any detail concerning the chemical elements, or univerſal firſt principles, with which it is probable we ſhall long remain unacquainted; we ſhall proceed to enumerate ſuch as experiment has ſhewn to be much more ſimple than other bodies. Theſe are, water, phlogiſton, earths, acids, and alkalis.

Chemiſtry is not yet ſufficiently advanced to enable us to determine whether theſe be the principles of all bodies; but it is certain that in the analyſis of every different ſubſtance we at length arrive at principles which may with propriety be claſſed under ſome of theſe heads. Hence we conjecture, that theſe principles, univerſally ſimilar to themſelves, and theſe only, enter into the compoſi-

tion

tion of all bodies, and that our being unable to exhibit them perfectly ſimilar is to be attributed to combinations, which the imperfection of the methods we make uſe of prevents our reſolving. Theſe principles are likewiſe to be regarded as ſimple, till future reſearches ſhall evince the contrary.

The true uſe of hypotheſes being to ſyſtematize and direct our future enquiries, this general method of abſtracting muſt be of great ſervice; but at the ſame time we muſt be careful not to deceive ourſelves by taking it for granted, that bodies, which reſemble each other ſufficiently to come under the ſame claſs, are really, though not apparently, ſimilar in every other reſpect. Experiment alone muſt aſcertain this ſuppoſition, and much remains yet to be done. From theſe and ſimilar conſiderations it is evident, that the general diviſion of bodies is not of any very great conſequence to ſcience in its preſent imperfect ſtate; and therefore that the controverſies and differences among chemiſts concerning firſt principles have tended but little to the advancement of knowledge.

The

The firſt of theſe principles, namely, water, is a very fuſible and volatile ſubſtance. It aſſumes the fluid ſtate in a leſs degree of heat than is neceſſary for vegetation, and is therefore in general met with in that ſtate. It is then very tranſparent, inodorous and taſteleſs. When its heat is diminiſhed to a certain degree, it becomes ſolid; not uniformly through all its ſubſtance at once, but ſome of its parts firſt aſſume a ſolid form in the ſhape of needles, croſſing each other at an angle of ſixty degrees, which continue to increaſe in number till the whole maſs of water is become ſolid. This act is called congelation, and the ſolid maſs, which is called ice, is much leſs tranſparent than before, and is augmented in magnitude about one tenth part. It is probable that the configuration of theſe needle-like parts may leave many inviſible vacuities in the ice, by which its magnitude is increaſed, and its tranſparency in a great meaſure deſtroyed; but, however this may be, the expanſion is made with a force ſo amazing, that no veſſel has yet been found ſtrong enough to reſiſt it. The honourable

Robert

Robert Boyle burſt a piſtol-barrel, and Dr. Hales burſt a bomb, the metal of which was one inch and a quarter thick, by freezing water contained within them.

Water in its fluid ſtate is elaſtic, and may be condenſed by preſſure. When the preſſure is removed it recovers its former dimenſions. But the difference of magnitude produced by the preſſures we are able to apply, compared with its magnitude when uncompreſſed, except by the gravity of its parts, is ſo extremely minute as to be almoſt inconſiderable.

The heat of water, and indeed all fluids of conſiderable volatility, may be increaſed to a certain degree, at which they become much agitated, and emit bubbles. This is called boiling, and happens at leſs degrees of heat accordingly as the fluid is more volatile. In open veſſels, fluids which are capable of boiling, cannot at that period be made to receive any increaſe of heat; but in cloſe and very ſtrong metallic veſſels water may be heated almoſt red hot. Upon this principle, the lighter the atmoſphere the ſooner the water boils; and if water, which has juſt ceaſed to boil, be placed

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in the exhauſted receiver of an air-pump it will boil again for ſome time, on account of the preſſure of the atmoſphere being removed.

This ſtationary or fixed point of heat is juſtly attributed to the copious evaporation. In fact, all evaporation produces cold. The water, therefore, is in no caſe ſo much heated by the fire, as it would have been if no evaporation had taken place. The greater the evaporation the leſs the effect of the fire: whence it follows, that at a certain period the evaporation muſt be ſo great, as that the effect of the fire ſhall be no more than juſt ſufficient to preſerve the heat of the water, without augmenting it. And in other fluids, this event muſt happen ſooneſt in thoſe which are moſt ſuſceptible of evaporation, or more volatile.

The production of cold, by evaporation, is a ſtrong argument in favor of thoſe who affirm that heat is ſomething more than a mere motion of the parts of bodies. How, ſay they, can cold be produced by evaporation, unleſs heat be a ſubſtance which is carried off by the vapors?

Water being ſuſceptible of two ſuch remarkable changes as congealing and boiling,

and

and that at degrees of heat which it is not difficult to produce, affords an excellent method for ſettling the fixed points of thermometers. For the heat at which water congeals, and likewiſe that at which it boils ſtrongly, under equal weights of the atmoſphere, are preciſe and invariable; and conſequently thermometers may be eaſily graduated from theſe two ſtates of heat, ſo that they ſhall always agree in like temperatures.

When water is rarefied by heat into the form of elaſtic vapour, it is called ſteam, and is more elaſtic the more it is heated. When the elaſticity of ſteam is equal to that of common air, it is much leſs denſe than the air, and conſequently muſt aſcend. It has already been obſerved, that this elaſticity of ſteam is turned to good account in the engine for raiſing water out of mines, &c.

If water be not a ſimple element it is compounded of principles whoſe mutual affinity is ſo great that they have never yet been ſeparated. When it is diſtilled, either ſeparately, or together with other matters, it is always recovered again in the form of water; ſo

ſo that it is uſually ſaid to be unalterable and indeſtructible.

Some philoſophers, by repeated diſtillations of water, have procured an earthy ſediment, and have from thence concluded that it was tranſmuted into earth: but it is generally thought, and there are experiments in confirmation of the opinion, that the glaſs-veſſels being abraded or diſſolved, may furniſh the earth, which is found to be of the nature of glaſs.

Water has an affinity with a very great number of bodies, and for that reaſon is never met with naturally free from heterogeneous matters, or abſolutely pure. The pureſt waters are rain and ſnow; but for nice purpoſes, water carefully diſtilled with a gentle fire is to be preferred to all other.

The next element, phlogiſton, is by many chemiſts termed fire; and in order to diſtinguiſh it from heat, which they likewiſe call fire, the phlogiſton is called combined fire, while heat is denoted by the terms elementary fire. But this manner of expreſſion preſuppoſes a certain theory of fire, which

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is by no means eſtabliſhed. We are ignorant whether heat be a mode or a ſubſtance; and to uſe the ſame term to expreſs both it and phlogiſton, which, in fact, is no more than the principle of inflammability, muſt tend to confuſe our notions, and betray us into a perſuaſion that we know more of the ſubject than we really do. It will therefore be neceſſary to keep as near the facts as poſſible.

Phlogiſton is that by which bodies, when in contact with pure air, and heated to a certain degree, are put into a ſtate of combuſtion, during which they are in a great meaſure decompounded, and moſt commonly, or perhaps univerſally, exhibit an appearance of flame.

Bodies may be divided into two claſſes, combuſtible and incombuſtible: the latter are only capable of being ignited, or made red hot, and begin to cool immediately upon removing the cauſe of their heat; whereas the former, when conſiderably heated, with acceſs of air, become inflamed, and continue to produce heat for a certain time, at the end of which they are, either entirely or in a great meaſure, deprived of that which made them

inflammable, and are reduced to the other claſs of incombuſtible bodies.

To vindicate the admiſſion of the cauſe of inflammability, or phlogiſton, among the elements, it will be neceſſary to ſhew, that it is a ſubſtance, and not a mere modification of the parts of bodies; and that it is univerſally ſo ſimilar to itſelf as to be eaſily diſtinguiſhed in all the various bodies which are combuſtible. For this purpoſe let us attend to the circumſtances attending combuſtion, and from thence make our inferences.

Firſt, All combuſtible ſubſtances which can be expoſed to great heat in cloſe veſſels, cannot, in that ſituation, be calcined or burnt; and in the open air the calcination is more quickly effected accordingly as the ſupply of pure air is greater. Secondly, If a combuſtible ſubſtance be inflamed, and afterwards included in a veſſel, with a ſmall quantity of atmoſpherical air, the combuſtion laſts for a certain time, and then ceaſes; this time, and conſequently that part of the maſs which becomes calcined, is greater or leſs acccording to the quantity of pure air included; and at the end of this time the air is found

found to be decompoſed, part being fixed and precipitated, and the remainder, which is about four-fifths of the original quantity, is ſo changed as to be unfit for the purpoſe of aſſiſting combuſtion, and is in ſome degree noxious. Thirdly, Sulphur may by combuſtion be deprived of its inflammable principle, by which means it is converted into the vitriolic acid; and again, the vitriolic acid, being properly treated with any inflammable ſubſtance, may regain the phlogiſton, and be converted into ſulphur; which ſulphur is poſſeſſed of the ſame properties, however different the properties of the inflammable ſubſtances may have been by which the phlogiſton was furniſhed. Laſtly, the calces of fixed compounds, as metals, may be reſtored to their original ſtate, by being treated with ſome inflammable ſubſtance; and the metal is in all caſes the ſame, however various the phlogiſtic ſubſtances may have been by which it was revived.

The natural deduction from theſe facts appears to be, that phlogiſton is a ſubſtance which is very ſimple and ſimilar to itſelf.

For what can the encloſing a combuſtible body in a cloſe veſſel do, but prevent the diſperſion of ſome ſubſtance? If calcination be no more than a change in the arrangement of the parts of bodies, why ſhould not heat affect this as well in cloſe as open veſſels? Is it not evident in the ſecond inſtance, that the phlogiſton becomes combined with the compounded fluid air, and cauſes it to depoſit one of its principles in the form of fixable air, while the calcination of the inflamed body goes forward; and does not the combuſtion ceaſe when the remaining principle or principles of the air, being ſaturated, are incapable of receiving any more phlogiſton? When ſulphur, by combuſtion, is tranſmuted into vapors, which when condenſed by means of water, and afterwards concentrated, are found to be the vitriolic acid, ought we not to conclude, that this very inflammable ſubſtance is converted, into a ſubſtance which is not at all ſo, by having loſt one of its principles, namely, phlogiſton? But when, on the other hand, the converſe of the problem is effected, by producing ſulphur from a well managed

managed combination, of the vitriolic acid with the inflammable principle of ſome other body, we can hardly retain a doubt of the exiſtence of this ſubſtance, and at the ſame time learn, from its effects, that it is ſimilar in all inflammable bodies. And this ſimiliarity of the phlogiſton is ſtill more evident from the reduction of the calces of metals; for if a metalline calx be properly treated with any inflammable ſubſtance, the external air being excluded, the metal, from which the calx was originally made, will be reproduced, as we have already obſerved.

The phlogiſton of inflammable bodies being ſeparable only when thoſe bodies are in contact with others with which it can combine; it is not probable that we ſhall ever be able to obtain it in an uncombined and detached ſtate. But it is by no means proper to ſpeak deciſively upon a ſubject in which ſo much remains yet to be inveſtigated.

Earth is diſtinguiſhable from all other ſubſtances by its great fixity. If it be a ſimple ſubſtance, it has not hitherto been exhibited alone and uncombined; and con-

ſequently there are many kinds of earths, which agree in the general property of fixity, but vary in ſeveral other reſpects. But we do not propoſe to enumerate and deſcribe them in the preſent chapter, and ſhall therefore ſpeak only of the general characters which are obſerved in bodies of this claſs.

There are few ſubſtances, if expoſed to violent heat, but will leave a reſidue, or, as the ancient chemiſts called it, a caput mortuum, which conſiſts, for the moſt part, of very fixed matters. That part of the reſidue which is either not at all, or with great difficulty, ſoluble in water, is called earth. Thus the calces of metals are called metallic earths, and precious ſtones, quick-lime, plaſter, clay, &c. are all earths, which reſemble each other in the properties of fixity and difficult ſolubility in water, and differ in other particulars. The hardeſt bodies in nature are of the claſs of earths.

Acids compoſe the next claſs of ſimple bodies. Theſe are ſo denominated from their taſte, which is acid or ſour, and are very numerous. There is ſome reaſon to imagine

imagine that one primary acid exiſts, and that all the others are combinations of this primary acid with other ſubſtances; but till this conjecture be more confirmed, we muſt conſider them as diſtinct and independent matters, which, from the reſemblance of their properties, are claſſed together. The general and diſtinguiſhing properties of acids are, 1. They affect the organ of taſte with a very peculiar ſapidity. 2. Their affinity with water is ſo great, that they cannot be exhibited in a dry and denſe uncombined form. 3. Concentrated acids added to water produce heat, if the water be in a ſtate of fluidity, but, on the contrary, if it be frozen, they produce extreme cold. 4. When much concentrated, they may be combined with phlogiſton. 5. They have a ſtrong tendency to unite with almoſt all bodies; hence they are very corroſive, and form the moſt active menſtruums. 6. They change the blue colours of vegetables and of their infuſions to a red. Thus, the ſyrup of violets, the tincture of heliotropium, and other ſimilar infuſions, are generally uſed to diſcover the preſence of an unſaturated acid

in bodies; but this criterion, though the moſt univerſal for that purpoſe, is not abſolutely ſo.

From the diſtinguiſhing properties of acids, it has been ſuſpected that pure acid is a combination of earth and water.

The laſt general ſpecies of bodies are alkalis. The four kinds of ſubſtances juſt enumerated are ſo far ſimple, that we have not been able to decompound them, ſo as to determine their primary principles with the ſmalleſt degree of accuracy. But in alkalis the caſe is different. They are procured by evident combination, namely, by the burning or putrefaction of ſubſtances in which they did not exiſt before, at leaſt in any conſiderable quantity. And they may be decompounded. Yet, becauſe the fixed alkali is capable of paſſing unaltered through a vaſt variety of chemical proceſſes, and has ſtrong affinities to many ſubſtances when in an uncombined ſtate, we have thought proper to arrange it in this place.

The chief properties of alkalis are, 1. They affect the organ of taſte with a burning, urinous taſte. 2. They have a ſtrong affinity

affinity with water, but may be eaſily obtained dry. 3. They produce heat by adding water to them. 4. They may be fuſed with a moderate heat, and in that ſtate diſſolve all earths. If the alkali be in a large proportion, the maſs or ſolution aſſumes the alkaline properties; but if the proportion of earth prevails, its properties obtain, and the maſs takes the form of glaſs. 5. If they be diſſolved in water, an earth is ſeparated, and falls to the bottom; and if the diſſolved part be dried, and again diſſolved, more earth is ſeparated; and ſo on for any number of times. 6. Their affinity with acids is ſo great, that they unite with them, howſoever they may be combined, and even detach them from every ſubſtance except phlogiſton and water. 7. They change the blue colours of vegetables, and their infuſions, to a green; but this criterion is not without its exceptions.

From the methods by which alkalis are procured, and the concomitant circumſtances, it is pretty well decided, that they are compounded of acid, of earth, and of a ſmall proportion of phlogiſton.

In the enunciation of ſciences which depend upon eſtabliſhed firſt principles, the nature of the ſubject dictates the order and arrangement. Simple truths are followed by more complicated deductions, in a natural and beautiful ſucceſſion. But in the infancy of knowledge, eſpecially that which depends upon experiment, every truth appears independent and cotemporary, while each attempt at explanation or analogy ſeems to demand a previous knowledge, in the learner, of all that has been done in the ſame way. Such is the ſtate of chemiſtry; and therefore, to preſerve that order which is eſſentially neceſſary to the conveying a general idea of ſcience, we have endeavoured to ſpeak curſorily upon almoſt every particular, and ſhall be more minute as we advance. The properties of earths, acids, and alkalis muſt be again reſumed, and in the mean time, we conclude this chapter with the following table.

TABLE

TABLE

OF

DENSE SUBSTANCES PRODUCED BY COMBINATION.

WATER	
combined with	produces
Phlogiſton	Ardent Spirit.
Phlogiſton & Acid	Reſins. Oils. Ether.
Earth	Lime Water. Plaſter.
Earth and Acid	Salt.
Acids	Fluor Acids.
Acid and Alkali	Neutral Salt.
Earth and Alkali	Liquor of Flints.
Alkalis	Fluor Alkalis.

PHLOGISTON	
combined with	produces
Water	Ardent Spirit.
Earth	Coal.
Earth	Metals.
Acid	Sulphur. Phoſphorus.
Acid and Water	Reſins. Oils. Ether.

EARTH	
combined with	produces
Water	Lime Water. Plaſter.
Water and Acid	Salt.
Phlogiſton	Coal.
Phlogiſton	Metal.
Acids	Salt.
Alkali and Water	Liquor of Flints.
Alkali	Glaſs.

ACIDS	
combined with	produce
Water	Fluor Acids.
Water and Earth	Salt.
Water and Alkali	Neutral Salt.
Water & Phlogiſton	Reſins. Oils. Ether.
Phlogiſton.	Sulphur. Phoſphorus.
Oils	Soap.
Alkali	Salt.
Metals	Salt.

ALKALIS.	
combined with	produce
Water	Fluor Alkali.
Water and Acid	Neutral Salt.
Phlogiſton	Liver of Sulphur.
Sulphur	Soap.
Oils	Liquor of Flints.
Earth and Water	Glaſs.
Earth	

CHAP.

CHAP. IV.

Of Earths.

THOSE ſubſtances which are compriſed under the general name of Earths, are very numerous and different, and the ſubdiviſions of this claſs have conſequently been various. Some authors have endeavoured to ſimplify the arrangement, and reduce the ſeveral kinds of earth to one or two general heads; while others, more minutely attentive to the differences, have been as careful to enlarge their catalogue. This Ariſtotelian element is met with in a prodigious variety of forms: ſtones, metals, clays, animal and vegetable ſubſtances, all furniſh a fixed principle, which is probably one and the ſame, but diſguiſed by combinations not yet diſcovered and analyzed. We ſhall endeavour to avoid either extreme of too much abſtraction, or too extenſive enumeration, and ſhall therefore divide earths into two claſſes, namely, cryſtalline

cryſtalline and abſorbent, which laſt we ſhall again ſubdivide into three, namely, calcareous, argillaceous, and gypſeous earths.

Cryſtalline earth, which is alſo called vitrifiable and ſiliceous earth, is by far the moſt ſimple in its appearance, and known properties, of any other. All precious ſtones, flint, ſand, gravel, and in general all minerals which have not a metallic appearance, and are ſufficiently hard to give ſparks with ſteel, are of this claſs, and may, from this laſt criterion, be eaſily diſtinguiſhed. Cryſtalline earths, and even glaſs, if rubbed together, become ignited, for the inſtant, at the place of contact, and emit a peculiar ſmell, which is ſomewhat ſulphureous. If this experiment be made in the dark, the cryſtal is luminous through its whole ſubſtance, which circumſtance has been thought perplexing by an eminent chemiſt, who did not conſider that it was no more than ought naturally to follow from the repeated reflections of the light from the internal ſurfaces.

Pure cryſtalline earth is inſoluble in acids, and does not combine with water, even ſo much as to form a paſte when finely pow-

dered. It ſuffers no fuſion nor alteration of weight by expoſure to heat; but ſands may be made to conglutinate a little by means of a violent fire: from which it ſeems, that their infuſibility depends on our not being able to apply a ſufficient degree of heat. It is called vitrifiable earth, becauſe many ſpecimens of it may be converted to glaſs, by the addition of a leſs quantity of fixed alkali than is required to effect the like with other earths.

The native maſſes of this earth affect a regular figure; eſpecially ſuch as are clear and tranſparent. Theſe, if unbroken, are in general bounded by a number of plane ſurfaces, whoſe diſtances vary, but whoſe angles of inclination to each other are uſually conſtant. Thus, rock cryſtal is commonly in the form of an irregular hexagonal priſm, whoſe ſix plane ſides make angles of 120° with the contiguous planes, and whoſe ends are terminated by one or more planes, which are uſually inclined to the axis of the priſm in an angle of about 40°.

The calces or earths of metals ſeem to be of this claſs, but altered by a remain-

ing portion of phlogiſton, by means of which they are ſoluble in acids, and may be vitrified without addition of any other ſubſtance.

Abſorbent earths are ſo termed from their property of imbibing water, with which they form either an intimate or a partial union. We ſhall proceed to deſcribe theſe under the general heads of calcareous, argillaceous, and gypſeous earths.

Calcareous, which are alſo called alkaline earths, are remarkable for the property of becoming cauſtic by means of fire. In fact, the heat decompounds them, and leaves the reſidue in that unſaturated ſtate in which cauſticity conſiſts. All native calcareous earths are ſufficiently ſoft to receive impreſſions from the point of a knife, and if broken, the ſurface appears porous and granulated, ſomewhat like ſugar. The opake ſpecimens are, limeſtone, ſeveral kinds of marble, chalk, the ſhells of fiſh, and other animal ſubſtances, when calcined after precipitation from an acid by fixed alkali. The tranſparent ſpecimens are ſeveral heavy ſpars of a laminated texture; among which is

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the ſubſtance called iſland-cryſtal, well known for its peculiar quality of dividing the rays of light into two nearly equal parts, one of which is refracted in a manner not conformable to the general rules of optics; whence it happens, that bodies ſeen through this cryſtal appear double. The ſtalactites, or ſtony iſicles, which hang from the roofs of caverns, are alſo of this claſs.

Calcareous earths which have not yet been burned, are called mild. When expoſed to a red heat for a conſiderable time, they loſe about half their weight, and are converted into quick-lime. In their mild or ſaturated ſtate, the quick-lime is combined with water, and a peculiar acid, which we ſhall have occaſion to deſcribe under the name of fixed air, both which are detached and driven off by the application of heat. Quick-lime, which is unmixed with other ſubſtances, may therefore be conſidered as pure calcareous earth.

The affinity between quick-lime and water is ſo great, that their union is attended with great heat. Quick-lime is actually diſſolved in water, but the quantity required

required to ſaturate a given quantity of water is very ſmall. Water thus impregnated has an acrid, alkaline taſte, and is called lime-water.

Acids diſſolve calcareous earths, and the combinations form various ſalts. If the calcareous earth be in a mild ſtate, when immerſed in the acid, the fixed air eſcapes in the form of bubbles, and the agitation of the fluid occaſioned thereby is called effervescence: but quick-lime, or cauſtic calcareous earth, being already deprived of its fixed air, is incapable of effervescing.

If water be poured on a ſmall quantity of quick-lime, it diſſolves a ſmall portion, and becomes lime-water. On the ſurface of this water is formed a ſcum or cruſt, which, breaking, falls to the bottom: a new ſcum is then formed, which likewiſe precipitates; and this continues for a certain time, at the end of which, the water becomes pure and inſipid, and the earth at the bottom is in a mild ſtate, and no longer ſoluble in water.

To explain this, it is to be obſerved, that the quick-lime, which is in ſolution near the ſurface of the water, attracts fixed air

from the atmoſphere, and becomes mild; and as mild calcareous earth is inſoluble in water, it forms a ſcum which continually increaſes, till it is too groſs to be ſupported at the ſurface, but breaks and falls down: the water ſtill retains its ſaturation, by diſſolving freſh quantities of the quick-lime at the bottom; the ſcum, therefore, continues to be formed, and to be precipitated as long as any quick-lime remains undiſſolved; at the end of which time the quick-lime, being all rendered mild by the continued addition of fixed air, the water is left pure and inſipid. The precipitate will effervesce with acids, and is in the ſame ſtate it was before it was burned.

Quick-lime poſſeſſes many of the properties of fixed alkalis, though not ſo ſtrongly. It turns blue vegetable infuſions to green, and unites with ſulphur, forming a compound, ſoluble in water like liver of ſulphur. It has likewiſe ſome action upon oils and ſpirits of wine. But it is not fuſible without the addition of an alkali, though calcareous ſpars and ſtalactites in a very fierce heat ſhew ſigns of a beginning fuſion.

Yet

Yet it is very remarkable, that theſe ſubſtances, though ſo refractory when alone, are nevertheleſs capable of aſſiſting the fuſion and vitrification of ſeveral other matters, as ſands and clays. This is a very difficult phenomenon to account for.

The earth called magneſia may be claſſed among calcareous earths, though its properties differ from thoſe of the latter in ſeveral reſpects; particularly in that of being not at all ſoluble in water.

Calcareous earths in fine powder form a paſte with water, which is not ductile, and dries very quickly. This is called mortar, and is durable in proportion as its cauſticity is more perfect. In order to give ſolidity to mortar, and render it more fit for the purpoſes of building, it is uſual to incorporate a quantity of ſand with the maſs.

The ſecond claſs of abſorbent earths is the argillaceous. Its diſtinguiſhing property is that of forming a very tenacious and ductile paſte with water, which may be moulded into veſſels that preſerve their form, and if gradually dried and expoſed to a ſtrong heat, bakes into a kind of ſtone called brick.

On this property of clays is founded the very uſeful and elegant art of pottery.

Boles, fuller's-earth, tile-earth, brick-earth, potter's-clay, pipe-clay, porcelain-clay, &c. are ſpecimens of argillaceous earth; but the pureſt earth of this claſs is that which is obtained from alum. Alum is a combination of the vitriolic acid with argillaceous earth: now, if fixed alkali be added to a ſolution of alum, it combines with the acid, and the earth is precipitated in the form of a very fine white powder.

Argillaceous earths mix very intimately with water, but are not diſſolved by it; for they ſubſide after being ſome time at reſt, but they are ſoluble in acids, particularly the vitriolic, with which they form alum, as we have already obſerved.

All clays which have been yet examined are found to contain vitriolic acid: and clay is found to obtain the properties of vitrifiable earth, by being well baked. In this laſt ſtate it is as hard as flint, and ſtrikes fire with ſteel; and if it be pulverized, it is found to poſſeſs no longer the property of combining with water or acids, but perfectly reſembles fine ſand.

ſand. For theſe reaſons clay is conſidered by many to be vitrifiable earth, altered by a combination with the vitriolic acid.

Pure clay reſiſts the moſt violent fire without fuſing, even though in contact with vitrified matters. Melting-pots or crucibles are made of clay mixed with groſs powder of broken earthen-ware. The veſſels which contain the melted matter in glaſs-houſes will ſometimes laſt a year, but they grow gradually thinner, probably from the action of their contents.

The laſt general head of abſorbent earths are gypſums, or plaiſter-earths. The peculiar and leading property of gypſum is, that if calcined and mixed with water to the conſiſtence of thick cream, it ſuddenly coagulates, and becomes conſiderably hard. From this circumſtance it is exceedingly uſeful for caſting ſmall ſtatues, or obtaining very accurate copies of bas-reliefs, as we ſee practiſed every day. In commerce it is called plaiſter of Paris.

Native gypſum is a ſoft, friable matter, and is found in large quantities in many parts of the earth. There are large mountains and hills in the neighbourhood of Paris, which are formed of this ſubſtance. It is always

cryſtallized, or regularly diſpoſed, but its forms are various. It is found in the form of large, tranſparent, ſhining thin plates, applied to each other ſo exactly, that they conſtitute maſſes as tranſparent as cryſtal. Theſe are called *lapis ſpecularis* by naturaliſts, from their large ſhining ſurfaces, like thoſe of mirrors. Again, large quantities of gypſum are found cryſtallized in ſtriæ, or threads, applied longitudinally to each other. This is called ſtriated gypſum. And laſtly; a very large quantity of gypſum is found in ſmall irregular cryſtals, adhering to each other, forming ſemitranſparent ſtones, called gypſeous alabaſter, which are very beautiful when white and pure. Notwithſtanding this diverſity of external appearance, theſe gypſums are perfectly ſimilar as to their chemical properties.

When expoſed to a conſiderable heat they loſe their tranſparency, and the adheſion of their parts is almoſt entirely deſtroyed, ſo that they may eaſily be crumbled into a fine white powder. If they be mixed with water in this ſtate, they ſoon acquire that ſolidity and conſiſtence which we have already mentioned as their diſtinguiſhing characteriſtic.

Gypſum

Gypſum has a conſiderable reſemblance to calcareous earth. It is ſoluble in water, to which it communicates the alkaline property of changing the blue infuſions of vegetables to green, as quicklime alſo does. It likewiſe has ſome action upon ſulphur, with which it forms a hepar or liver. But it does not diſſolve or effervesce with acids. In fact, if a ſufficient quantity of acid be poured upon gypſum, a kind of ſolution may be made; but the gypſum does not properly combine with the acid; for it may be recovered in its original ſtate merely by cryſtallization.

The heat which is commonly produced in furnaces is inſufficient to melt gypſeous earths without addition; but by a more violent and long-continued heat it may be fuſed. It may be melted by the ſolar rays collected by a concave mirror, and a very ſmall piece may be made to melt and run into a hard white globule, by means of an enameller's lamp. But in this laſt experiment it may be ſuppoſed to receive phlogiſton from the flame.

If gypſum be boiled with a mild fixed vegetable alkali, the water is found to contain vitriolated tartar, and the earth at the bottom

of the veſſel becomes calcareous earth. We muſt obſerve, that vitriolated tartar is the name of a ſalt compoſed of the vitriolic acid, and fixed vegetable alkali. The explanation of theſe appearances is evidently this; two decompoſitions and two new combinations take place by means of what chemiſts call a double affinity: the fixed vegetable alkali combines with vitriolic acid, which it muſt obtain from the gypſum, and forms vitriolated tartar: while the fixed air quits the mild alkali, and combines with the earth of the gypſum, forming mild calcareous earth, which may be converted into quicklime by burning. From this it is obvious, that the component parts of gypſum are calcareous earth, and the vitriolic acid.

If gypſum be diſtilled with powder of charcoal, a volatile ſulphureous acid and true ſulphur are obtained. Theſe being likewiſe the produce of charcoal, or other phlogiſtic matters treated with the vitriolic acid, are an additional confirmation that it exiſts in gypſum. But the exiſtence of the two principles in gypſum is placed beyond doubt, by the artificial production of this ſubſtance, which is effected

effected by ſaturating the acid of vitriol with calcareous earth. This combination is called ſelenites.

From this account we may explain all the properties of gypſum. As it is properly a ſalt, it wants hardneſs, is tranſparent, ſoluble in water, and capable of cryſtallization. It cannot be combined with any acid, becauſe it is naturally ſaturated with the vitriolic acid. Its calcination, by which the adheſion of its parts is deſtroyed, conſiſts in the expulſion of the water which entered into its chryſtallization: and when it is again combined with water, it cryſtallizes, or grows ſolid, very ſuddenly and confuſedly, becauſe it requires a very great quantity of water to hold it in ſolution. And the properties of quicklime, which gypſum obtains in a ſmall degree, may be attributed to the ſubtraction of a part of the vitriolic acid, which combining with the phlogiſton of the fuel, becomes ſulphur, and is burnt; by which means a part of the calcareous baſe of the gypſum is left uncombined: and gypſum is accordingly obſerved to emit a ſmall flame when calcined in an open fire, or heated by a lamp and blow-pipe.

CHAP.

CHAP. V.

Of Acids.

THE affinities of bodies to each other are ſo numerous, that we find no bodies in nature but are in a ſtate of compoſition. Water is in general purified by diſtillation, earth by calcining, and acids and alkalis are never met with pure, but muſt be obtained by chemical methods. We ſhall here proceed to deſcribe the ſeveral acids, and the ſubſtances from which they are procured.

Acids are obtained from the mineral, vegetable, and animal kingdoms, and are accordingly denominated. Mineral acids are, 1. The vitriolic acid. 2. Nitrous acid. 3. Marine acid. 4. Acid of borax. Vegetable acids are, 1. Acetous acid. 2. Vinous acid, or acid of tartar. 3. Eſſential acid of vegetables, as lemons, &c. 4. Acid obtained by diſtillation of vegetables. Animal acids are, 1. Phoſphoric acid. 2. Acid obtained by diſtillation from ants. 3. And the poiſons of ants,

ants, bees, waſps, and other venomous animals are probably acids. Perhaps the number of acids may be much larger; or perhaps ſome of theſe may be only modifications of other primary acids; or they may perhaps be all modifications of the one primary acid; namely, that of vitriol, as the great Stahl conjectures.

The vitriolic acid, improperly called oil of vitriol, is obtained chiefly from ſulphur, which is ſometimes found native, but much oftener extracted from a mineral known by the name of pyrites. Pyrites is a hard ſubſtance, capable of giving ſparks with a ſteel, from whence it has its name. It has almoſt always a metallic, yellowiſh or white appearance, and is often very regularly ſhaped; but the forms are ſo various, that it is impoſſible to enumerate them. Theſe bodies are ores of copper, arſenic or iron; but the proportion of ſulphur is very great to that of the metal. The moſt common kind are thoſe which contain iron, and are generally of an irregular ſpherical or cylindrical figure, and when broken appear to be internally compoſed of needles or radii, which unite in the center or in the axis of the ſolid.

Theſe

Theſe pyrites, which are found to conſiſt of much ſulphur, ſome iron, and a ſmall quantity of argillaceous earth, are decompounded by expoſure to the air. For the phlogiſton of the ſulphur has a tendency to unite with the air, and the vitriolic acid of the ſulphur tends to combine with the iron. Theſe two actions gradually decompoſe the ſulphur, eſpecially if a proper degree of moiſture be added; for the vitriolic acid diſſolves iron more readily when ſomewhat diluted. Thus the phlogiſton flies off into the air, and the acid, combining with the iron, forms a ſalt, called vitriol, the whole maſs falling into an efflorescence, or powder. This decompoſition, and new combination, is attended with heat; and in ſome circumſtances, chiefly depending on the quantity of the pyrites and their moiſture, actual fire is produced. Combuſtion, depending on the rapid combination of phlogiſton with pure air, as has been already obſerved, it is not to be wondered that a too copious diſengagement of that principle ſhould produce ignition in the preſent inſtance.

The efflorescence being diſſolved in water, with the addition of pieces of old iron, to combine

combine with any part of the acid, which might be in a diſengaged ſtate, produces cryſtals of vitriol, by the evaporation of the water. This vitriol is of uſe in the arts, and was formerly the ſubſtance from which the vitriolic acid was procured. For this purpoſe this ſalt was deprived of part of the water of its cryſtallization, by means of fire, which changes it into a red ſubſtance, called colcothar. The colcothar being ſubmitted to diſtillation, with a ſtrong heat, affords a ſulphureous acid, which was afterwards rectified by a ſecond diſtillation; a volatile, weak ſulphureous acid came over into the receiver, which was called ſpirit of vitriol; and the fixed, heavy, and concentrated acid, which remained in the retort, was called oil of vitriol, and is the pure vitriolic acid.

But this troubleſome operation is now avoided, and the vitriolic acid is obtained from pyrites, by a much ſhorter and cheaper proceſs. By a ſtrong heat ſulphur is ſublimed in cloſe veſſels, from pyrites not yet fallen into efflóreſcence, and from the ſulphur, by burning, is obtained the vitriolic acid. Every one knows what a ſtrong and ſuffocating vapor exhales

exhales from burning ſulphur; but the chief difficulty conſiſts in condenſing it. In great works, leaden veſſels are uſed, called houſes, of a priſmical form, the baſes of which are about ſix feet long and four broad, and their height about ten feet. The bottom of each of theſe veſſels is covered with a ſmall quantity of water, to aſſiſt the condenſation of the vapor. Above the water is placed a ſmall veſſel, capable of containing a few pounds of ſulphur, to which a ſmall portion of nitre is added; becauſe the nitre in burning actually produces a quantity of pure air, by means of which the combuſtion of the ſulphur may be continued a longer time without acceſs of freſh air. The veſſels are to be filled with the vapor of hot water, and their ſides wetted with the condenſed ſteam: then the ſulphur is to be kindled by touching it with a red hot iron: the vapor of the burning ſulphur riſes ſlowly; and when it has riſen as high as the mouth of the great veſſel, this muſt be ſtopped, or very nearly ſtopped, that the vapor may be confined. The ſulphur continues to burn till the air contained within the veſſel and the nitre be no longer capable of maintaining

taining the combuſtion. The vapor remains a conſiderable time before it be intirely condenſed, notwithſtanding that this condenſation is facilitated by the water in the veſſel, and eſpecially by the ſteam of water with which the veſſel was previouſly filled. When all the vapor of the ſulphureous acid is at laſt condenſed, the ſulphur is to be again kindled, and more added, if neceſſary, and the proceſs repeated as before. When a ſufficient quantity of acid is collected, it is to be taken out of the veſſel; and after it has loſt its ſulphureous or volatile quality by expoſure to air, it is concentrated, by diſtilling off the ſuperfluous water. This is the vitriolic acid; and its fixity is ſo great, that it cannot be made to boil by a heat leſs than ignition. The laſt portions of water are retained ſo ſtrongly, that they cannot be driven off but by a ſtrong and continued heat; and it may be ſo far dephlegmated as to appear in a concrete ſtate in the uſual temperature of the atmoſphere.

The rationale of all this is obvious. The combuſtion cauſes the phlogiſton of the ſulphur to unite with the air, and raiſes the vi-

triolic acid, which is ſtill ſo volatile, on account of a remaining portion of phlogiſton, as not to be eaſily condenſed, without combining it with a more fixed ſubſtance, as water. When the contained air is ſaturated with phlogiſton, the combuſtion ceaſes, and the water becomes ſlightly acid by the condenſed vapors of vitriolic acid, which acid is rendered more pure by expoſure to the air with which its phlogiſton combines.

The pureſt vitriolic acid is entirely free from ſmell or colour, and its ſpecific gravity, when well concentrated, is to that of water as 17 to 8. It poſſeſſes all the characteriſtic properties of acids more ſtrongly than any other acid, and its affinity with water is ſuch, that it unites with it with an aſtoniſhing activity and impetuoſity; and the heat reſulting from the re-action of theſe two cold liquors is ſo great, that in an inſtant it equals, and even much ſurpaſſes, that of boiling water.

We have already mentioned the production of ſulphur, by treating the vitriolic acid with any inflammable ſubſtance, and have applied the fact to prove that phlogiſton is ſimilar to itſelf in all bodies which contain it. It is not therefore

therefore for the ſake of making ſulphur, which can be more conveniently procured from pyrites, but in order to eſtabliſh this important truth, that the experiment is made. The chief circumſtance to be attended to in the proceſs is, that the vitriolic acid be very much concentrated, and the inflammable ſubſtance very dry: for, as the vitriolic acid has a very ſtrong affinity to water, its tendency to combine with phlogiſton muſt be weakened in proportion to the quantity of water which preſents itſelf. If, therefore, the vitriolic acid in a fluid ſtate, that is to ſay, combined only with water, be ſubmitted to diſtillation together with oil of turpentine, or any inflammable ſubſtance containing water, the phlogiſton is made to combine with the acid in that weak manner which conſtitutes ſulphureous acid; which is ſo volatile that it cannot be condenſed in the heat of the atmoſphere, without preſenting another more fixed ſubſtance to which it has an affinity, as we have already obſerved. But towards the end of the operation, when the reſidue of the oil is reduced to the form of a coal, and the vitri-

olic acid exceedingly concentrated, the combination forms true ſulphur, which ſublimes to the neck of the retort.

This method is ſimple and obvious, but is attended with ſome danger of burſting the veſſels, by a too rapid converſion of the acid into vapor. The more ſtudied method of Stahl is to be preferred, which is this: vitriolic acid being combined and ſaturated with fixed vegetable alkali, forms a ſalt called vitriolated tartar: to this ſalt is added an equal quantity of fixed alkali, together with half the quantity of powdered charcoal. The whole muſt be put into a crucible, and well mixed together; and the crucible, being covered, is to be expoſed to a ſtrong heat ſuddenly applied, and continued a very ſhort time. The melted mixture being poured out on a ſtone, previouſly greaſed, coagulates by cold, and is found not to differ from ordinary liver of ſulphur, except in the admixture and ſolution of a ſmall portion of charcoal. If this liver of ſulphur be diſſolved in water, and an acid added, a precipitate falls down, which is ſulphur.

In

In the table at the end of chap. 3. alkali and ſulphur are ſaid to produce liver of ſulphur. In order that the juſt mentioned proceſs may be more eaſily underſtood, it will be proper firſt to deſcribe this ſubſtance. If equal parts of fixed alkali and ſulphur be melted together, a compound is formed of a brick-duſt color, which is from thence called liver of ſulphur. This combination may alſo be formed by boiling theſe two ſubſtances in water, but the method is leſs advantageous, and therefore leſs uſed than the other. In this compound the alkali is united with the acid, but much leſs ſtrongly than if the acid were not at the ſame time combined with the phlogiſton. The combination between the acid and the phlogiſton is alſo rendered leſs ſtrong and perfect; for the power of ſaturation in the acid, being probably limited, cannot be applied to the alkali without either letting go, or at leaſt retaining leſs forcibly the phlogiſton. From this it follows, that the phlogiſtic and alkaline properties muſt be the moſt perſpicuous in the compoſition. The phlogiſton being weakly attached, is continually eſcaping and combining with the air;

and the alkali, not having its whole tendency to union ſaturated, renders the compound ſoluble in water, and even attracts the vapors from the atmoſphere, by which it deliquiates, or becomes moiſt. And therefore liver of ſulphur expoſed to the air continually emits phlogiſtic vapors of a faint and putrid ſmell, by which the air is vitiated, and at the ſame time it grows more and more moiſt, till at length nothing remains but a deliquium containing vitriolated tartar, that is to ſay, vitriolic acid combined with fixed alkali.

Pure vitriolic acid has ſo great an affinity with fixed alkali, that it diſlodges every other acid with which the alkali may be united, and combines with it itſelf. But in freſh liver of ſulphur, the vitriolic acid, being already combined with the phlogiſton, is weakly attached to the alkali, as has been ſaid, and for that reaſon may be eaſily ſeparated from it even by the weakeſt acid. Thus, liver of ſulphur being diſſolved in water, the alkali may be detached by pouring in any other acid, with which it unites: and conſequently the vitriolic acid and phlogiſton being left at liberty to exert their whole mutual action, cohere

ſtrongly, and form again the compound ſulphur, which not being ſoluble in water, immediately precipitates in the form of powder. A ſtrong phlogiſtic vapor eſcapes during this proceſs; from which we may conjecture, that a part of the vitriolic acid of the ſulphur is detached in a volatile form during the fuſion by which the liver is made, and that the remaining phlogiſton of that part combines with the alkali: ſo that when the decompoſition takes place, the vitriolic acid, uniting ſtrongly with its proper quantity of phlogiſton, and the alkali uniting with the ſuperfuſed acid, that portion of phlogiſton which was united with the alkali is left in a diſengaged ſtate, and readily combines with the air. That theſe vapors are phlogiſton, appears from their producing the ſame diminution and noxious qualities in the air, and even from the changes they produce in metallic ſubſtances, the calces of ſome of which are even revived by them.

Theſe things being duly conſidered and attended to, there will be no difficulty in accounting for every thing that happens in Stahl's proceſs for making ſulphur. The acid in vitriolated tartar is in a ſtate of much concen-

tration, and the ſuperaddition of fixed alkali tends to increaſe that concentration, by attracting the water which entered into the cryſtals of the ſalt. In this ſtate, charcoal, that is to ſay, phlogiſton combined with an earthy baſe, is preſented. The vitriolic acid has a greater affinity to the phlogiſton than to any of the other principles which enter into this compound, but, for the reaſons mentioned in the firſt and ſecond chapters of this ſection, the affinities are not exerted without heat. Heat therefore being applied, the principles of the whole maſs arrange themſelves ſo as to ſatisfy, as much as poſſible, their ſeveral elective attractions: the vitriolic acid forms ſulphur with the phlogiſton, and the alkali holds that ſulphur in ſolution, forming the liver, while the charcoal is in part decompounded, in part diſſolved, and in part merely mixed with the compound.

The next mineral acid is that of nitre; but whether the nitrous acid be really a mineral ſubſtance or no, is not eaſy to determine. It is obtained from nitre, a ſalt whoſe original is very dubious, but which is, for the moſt part, obtained by an artificial combination of an alkali with the ſaline part of animal or vegetable

vegetable ſubſtances, which have completely undergone the putrefactive fermentation. We ſhall be more particular when we come to ſpeak of this ſalt, which is found to conſiſt of a fixed alkali, combined with a peculiar acid. This acid is called the nitrous acid.

To detach the acid of nitre, which is uſually called ſpirit of nitre, from its alkaline baſe, the acid of vitriol is made uſe of, on account of its ſtronger affinity with the alkali. For this purpoſe martial vitriol, deprived of its ſuperabundant water by calcination, or elſe the pure concentrated vitriolic acid is added to nitre, and the whole ſubmitted to diſtillation in a reverberatory furnace. In either caſe the vitriolic acid combines with the alkali of the nitre, and forms vitriolated tartar, while the nitrous acid, being diſengaged, paſſes over in the form of red fumes into the receiver, in which it becomes condenſed. If the calcined vitriol be made uſe of in this proceſs, the nitrous acid is more red and ſmoking than in the latter caſe; which circumſtance is probably owing to the phlogiſton, which is one of the principles of the iron. Theſe methods are uſually adopted by chemiſts, but the ni-

trous acid, called aqua fortis, which is uſed in the arts, is obtained from nitre mixed with clay, previouſly well dried. The decompoſition takes place as before, and is in general attributed to the vitriolic acid, which, as we have already obſerved, is found in all clays. But if we conſider that the quantity of vitriolated tartar found in the reſiduum is very ſmall, and that the nitrous acid may be diſtilled from nitre mixed with clay already baked, as broken tobacco-pipes, or even with pure vitrifiable ſand, we have reaſon to conclude that theſe intermediate ſubſtances are chiefly uſeful, by preventing the nitre from melting into a coagulum, by which means a more extenſive ſurface is left for the eſcape of the nitrous acid, which comes over principally becauſe it is much more volatile than the alkali with which it was combined.

In the diſtillation of nitrous acid, care muſt be taken to apply the heat very gradually, as a neglect of this precaution may be attended with dangerous exploſions.

Nitrous acid, as it is uſually met with, is of a yellow ſtraw color, and continually emits vapors of the ſame colour, and of a peculiar ſuffocating

ſuffocating ſmell. But this color ſeems to be accidental, and to depend upon ſome combination of phlogiſton, with the mode of which we are unacquainted; for it may be deprived of it by a ſlight degree of heat without affecting its other properties. This acid is lighter than the vitriolic, and, when in the utmoſt concentration that can be obtained by ordinary means, is to the weight of water as 19 to 12. It unites with water with a conſiderable heat and ebullition; and while they are mixing, the maſs aſſumes a blue or deep green color. If expoſed to the air it attracts the humidity from thence, but not ſo ſtrongly as the vitriolic acid.

All the diſtinctive and general characters of acids are found in the acid of nitre. Many chemiſts are of opinion that it is no more than the vitriolic acid combined with phlogiſton in the proceſs of putrefaction, by which nitre is obtained: and they ſupport their opinion by obſerving, that the volatile ſulphureous acid, which is evidently nothing more than the vitriolic acid combined with phlogiſton, reſembles the nitrous acid, and approaches to it in thoſe particulars in which it

differs

differs from the vitriolic. It is even aſſerted, that the converſion of the vitriolic into the nitrous and marine acids has been effected; but the aſſertion has not yet been proved.

Nitrous acid is one of the moſt powerful menſtruums in chemiſtry, not that it is the ſtrongeſt acid, for in ſtrength it is inferior to vitriolic acid, and even in certain circumſtances to marine acid; but on account of the facility, the quickneſs and the activity with which it diſſolves moſt ſubſtances.

The affinity of nitrous acid to phlogiſton is very great. In fact, phlogiſton ſeems to be the intermediate ſubſtance by means of which it holds moſt bodies in ſolution. If to nitrous acid, which is ſaturated, with iron for example, a freſh portion of iron be added, it will diſſolve that likewiſe, and let fall a precipitate at the ſame time, which is a true calx of iron. Now, whether the precipitate be the iron laſt added, which is calcined by the ſubtraction of its phlogiſton, or whether this laſt be diſſolved, and a part of the former precipitated, the reſult is the ſame, namely, that the affinity of nitrous acid to iron depends on the phlogiſton of the latter. And

tin,

tin, which has the leaſt attachment to its phlogiſton of any metal, as appears by the eaſe with which it is calcined by fire, is very imperfectly diſſolved by this menſtruum; by far the greater part being calcined and precipitated without addition of any other ſubſtance.

We have ſeen in many inſtances that heat is produced by the concurrence, and, perhaps, colliſion, of two ſubſtances, whoſe mutual affinity is very ſtrong: and we have obſerved, that the mutual affinity of phlogiſton and pure air is very probably the cauſe of that increaſe and continuance of heat which is ſeen in bodies which are decompoſed by the act of combuſtion. From every experiment there is reaſon to conclude, that the affinity between the nitrous acid and phlogiſton is very great: and from very modern experiments it has been diſcovered, that this acid is the principal element which enters into the compoſition of pure air. By the help of theſe conſiderations and facts, we may venture to give a conjectural account of the ſtrong and ſurpriſing combuſtion which is produced by

the application of ſubſtances containing phlogiſton to the acid of nitre.

Concentrated nitrous acid being poured on any kind of oil produces great heat and effervescence, and in proper circumſtances even accenſion. Oil of turpentine, of ſaſſafras, or of guyac, and in general any thick oil, into the compoſition of which little water enters, may be inflamed by the ſimple affuſion of the acid. But the ſucceſs of the experiment is much more certain, and may even be obtained with all other oils, if the nitrous acid be previouſly mixed with the vitriolic. The oil is firſt put into the veſſel, in which the inflammation is intended to be made. Then the veſſel containing the acid is to be tied to the end of a long pole, that the operator may not be hurt by the burning matter, which ſometimes is thrown to a conſiderable diſtance on all ſides. One-half or two-thirds of the acid is poured at once. A conſiderable ebullition is excited; the oil becomes black, thick, and ſometimes inflames. But if it does not take fire in four or five ſeconds, the remainder of the acid muſt be poured on the part which appears

appears thickeſt and drieſt, and then the inflammation of the mixture ſeldom or ever fails to take place.

In moſt chemical experiments, and particularly in this, the event is more certain when large quantities of the materials are uſed. Leſs than an ounce of each ought not to be uſed; but when a pound of ſtrong nitrous acid is poured on an equal quantity of oil of turpentine, the effect is grand and aſtoniſhing. A thick column of flame and ſmoke, of above twenty feet in height, is inſtantaneouſly produced.

Does not this remarkable phenomenon depend immediately on the ſtrong affinity between the nitrous acid and the phlogiſton of the oil? In order that this affinity may exert itſelf as much as poſſible, it is neceſſary that both ſubſtances ſhould be in the moſt uncombined ſtate. The oil ſhould contain very little water, and the acid muſt be very much concentrated. The addition of vitriolic acid to the acid of nitre increaſes this concentration, by ſubtraction of part of its water, to which the former has a greater affinity; and it may likewiſe tend to dephlegmate the oil

at

at the time of affuſion. And ſince the concurrence of two bodies which ſtrongly attract each other, is known to produce heat; the degree of that heat will depend on the ſtrength of the affinity. If that be ſufficiently great, accenſion may be actually produced, and the bodies in the inſtant of combuſtion may be volatilized and diſperſed on all ſides in a ſtate of ignited vapor. Such is probably the caſe in the inſtance before us.

The third mineral acid is the marine, or muriatic acid, called alſo ſpirit of ſalt. It is obtained from common ſalt, and derives its names from thence. If the vitriolic acid be added to common ſalt, the marine acid immediately riſes in white fumes, which are not eaſily condenſed. For this reaſon, in diſtilling ſpirit of ſalt, a retort is uſed which differs from the common ſort, in having a tubular opening, into which vitriolic acid, equal to one-third of the weight of the ſalt, may be poured at ſeveral times; and becauſe of the difficulty of condenſing the vapors, it is uſual to dilute the vitriolic with water; ſo that the vapors of the water, paſſing over into the receiver together with the acid, aſſiſt the

the condenſation, upon the principle already explained, in ſpeaking of the vapors of ſulphur. But in common practice dried clay to the quantity of about twice the weight of the ſalt is uſed, inſtead of vitriolic acid. After the diſtillation, a ſalt is found in the retort, called Glauber's ſalt, which differs from vitriolated tartar in its baſe: for the baſe of common ſalt is the fixed foſſile alkali, and differs in ſeveral particulars from the fixed vegetable alkali, which is the baſe of common nitre.

The marine acid is generally of a light yellow, and emits white and ſuffocating fumes, which are not viſible, except in the open air. There is reaſon to believe that its colour is accidental, and that it ought to be clear and tranſparent when pure. Being more volatile than either the vitriolic or nitrous acids, it cannot be concentrated near ſo much; and its affinity with phlogiſton is ſo weak, that we are not aſſured that it can at all be combined with it, unleſs by the help of ſome intermediate ſubſtance. It therefore in general diſſolves metallic ſubſtances leſs, but their calces more readily than other acids: and from this property it adheres to, and precipitates with

with the calces of metals, which are held in ſolution by the vitriolic, or nitrous acids, and forms marine ſalts with metallic baſes. By this means it may be made to unite with ſeveral metals with which it was incapable of forming any union while in their metallic or phlogiſtic ſtate.

Yet by an artful management of this acid with ardent ſpirits, a very volatile and inflammable fluid may be obtained by diſtillation, called ether. There are alſo vitriolic and nitrous ethers, though the vitriolic is the only one found in the ſhops. This combination ſeems to be an intermediate ſubſtance between ardent ſpirit and oil, and partakes of the properties of both.

The marine acid poſſeſſes all the common properties of acids.

The acid of borax is better known by the name of ſedative ſalt. It is obtained from borax, which is a ſaline ſubſtance, brought from the Eaſt-Indies, whoſe origin is unknown to us. If borax be diſſolved in hot water, and the ſolution filtred, and any one of the three mineral acids be added, by a little at a time, till the liquor be ſaturated, and even

even have a ſlight exceſs of acid; a great number of ſmall ſhining laminated cryſtals will be formed in the liquor when cool. Theſe muſt be waſhed with a little very cold water, and are the ſedative ſalt. The remaining liquor of the ſolution is found to contain a ſalt exactly the ſame as would have been produced by the combination of the acid made uſe of with mineral alkali. If the vitriolic acid be uſed, it contains Glauber's ſalt, if the nitrous acid, quadrangular nitre, and if the marine acid, common ſalt. And, on the other hand, if ſedative ſalt be added to the mineral or fixed foſſile alkali, borax is produced.

Sedative ſalt therefore acts as an acid in the combination of borax by neutralizing the alkali; but it is deficient in moſt of the other properties of acids. It is a concrete ſubſtance, difficultly ſoluble in water, and may be fuſed into a kind of glaſs, without altering its properties: and it has neither the acid taſte nor the property of changing blue vegetable infuſions to red. Many chemiſts believe it to be a combination of the vitriolic acid, with a vitrifiable earth; but as the attempts to ana-

lyze it have not hitherto been ſucceſsful, we have choſen to arrange it in this place. Yet, nevertheleſs, when we ſpeak of mineral acids we would be underſtood to conform to the uſual acceptation, and to mean the vitriolic, nitrous, and marine acids.

The acetous acid is produced by a ſecond fermentation from vegetable ſubſtances, which have already undergone the vinous or ſpirituous fermentation. This ſecond fermentation is attended with heat, and requires peculiar management. The chief circumſtance to be attended to is to prevent the ſpirituous part of the wine from eſcaping; for the greater the quantity of ardent ſpirits, or, in other words, the ſtronger the wine, the more briſk and acid the vinegar. This acid is combined with much water, and oily or mucilaginous matter, ſo that it cannot be obtained in a ſtate of ſuch concentration as the mineral acids. If vinegar be diſtilled, a purer acid may be obtained, but weaker: if it be expoſed to freeze, and the ice taken away, the remainder is concentrated in a conſiderable degree. But the higheſt degree of concentration of this acid is obtained by combining it with alkalis, earths,

or metals, and afterwards decompoſing by means of fire. Thus, verdigriſe, which is copper corroded by the acid of grapes, being diſſolved in hot diſtilled vinegar, forms by evaporation cryſtals of a ſalt which is improperly called diſtilled verdigriſe: if this ſalt be ſubmitted to diſtillation, the water which entered into the formation of the cryſtals comes firſt over; and afterwards, when the retort begins to be red hot, the acid paſſes over, partly in white clouds, and partly in drops. This ſtrong acid has a very pungent and ſuffocating ſmell, and is called radical vinegar, or, improperly, ſpirit of Venus.

The acetous acid has all the general properties of acids. Radical vinegar, when well concentrated, eaſily cryſtallizes, or takes a ſolid form without addition. It has, beſides, the remarkable property of burning entirely away, like ardent ſpirits, if heated in an open pan and ſet on fire. This, added to the obſervations which are ſuggeſted by the mode of its formation, tends to prove that ardent ſpirit enters into the compoſition of vinegar.

Vinous acid, or tartar, ſeems to be nothing elſe than the acetous acid combined with a portion of fixed vegetable alkali. It is probable that all wines undergo an inſenſible fermentation for a very long time after the ſenſible ſpirituous fermentation has ceaſed; whence they are altered and meliorated by age. Whether this be a beginning acetous fermentation, which is never completed for want of air, or whether it be ſomething totally different, cannot be determined without expreſs obſervation and experiment; but it is during this proceſs, that a concrete ſaline oleaginous encruſtation is formed on the inſide of the caſk. This matter exhibits all the ſigns of the preſence of an acid, and is called tartar. Tartar, being diſſolved in hot water and filtrated, takes the form of cryſtals by cold; which cryſtals, being farther depurated by boiling in water in which clay is diffuſed, are at length deprived of all their oleaginous matter, and partly by cooling and partly by evaporation, are again cryſtallized. In this laſt form they are uſually called cream of tartar.

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In order to diſcover whether this purified tartar, or cream of tartar, be a ſimple acid or a compound ſalt, it is diſſolved in water, and the ſolution rendered neutral, that is to ſay, neither acid nor alkaline, by adding ſome fixed vegetable alkali. The ſalt produced by evaporation and cooling, is called ſoluble tartar. Again, to a ſolution of cream of tartar is added mild calcareous earth, till the acidity is deſtroyed, and no more effervеſcence produced: a copious white ſediment falls to the bottom, and the liquor is found to contain ſoluble tartar exactly as before. Laſtly, if diluted vitriolic acid be poured on the white ſediment, it will become a gypſum, or vitriolic ſalt with baſis of calcareous earth, and the liquor will contain an acid, to which, if fixt vegetable alkali be added, it will, by cryſtallization become cream of tartar, or, if the ſaturation was complete, ſoluble tartar.

It is not difficult to explain this. If cream of tartar be a ſimple acid, the ſoluble tartar produced in the firſt inſtance muſt be a combination of this acid with vegetable alkali. But, in the ſecond experiment,

we have a proof that it is not ſimple; for inſtead of forming a ſimple combination with the calcareous earth, two diſtinct ſubſtances are produced, namely, a white precipitate, and a ſoluble tartar in the liquor. The precipitate is found to be a ſalt; for upon combining the vitriolic acid with its calcareous baſe, an acid which it muſt have acquired from the tartar is detached. And this acid, being combined with vegetable alkali, and producing either cream of tartar, or ſoluble tartar, according to the proportions, evidently ſhews the component principles of thoſe ſalts. Tartar then is a combination of an acid, not yet ſufficiently examined, with the fixed vegetable alkali, but in which there is a ſuperabundance of acid. If a ſufficient quantity of alkali be added to engage the ſuperfluous acid, a neutral ſalt is produced, or if that ſuperfluous acid be combined with calcareous earth, and precipitated in the form of a difficultly ſoluble ſalt, the remainder of the tartar, being deprived of its ſuperabundant acid, muſt be converted into the ſame neutral ſalt, or ſoluble tartar.

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The exiſtence of vegetable alkali as a principle in tartar, is likewiſe proved, by treating it with the mineral acids. For by combining with its baſe, they ſeverally form preciſely the ſame ſalts as would have been produced by their direct combination with fixed vegetable alkali.

The eſſential ſalts of vegetables, and the acids which enter into their compoſition, have not yet been enough enquired into. An experimental analyſis of theſe ſubſtances cannot fail to furniſh very intereſting and valuable knowledge. The great difficulty in this reſearch conſiſts in depriving the ſalts of that mucilage and ſaponaceous matter, which not only prevents their cryſtallizing in water, but likewiſe makes them more ſubject to alteration when ſubmitted to fire. The acid obtained from ſugar, by treating it with the nitrous acid, is found to be much more powerful, with reſpect to the chemical affinities, than the acetous acid.

We know very little concerning the acids which are procured from vegetable, or even animal matters, by diſtillation; neither have-

thoſe ſubſtances, which are remarkable as poiſons in venomous animals, been examined with any degree of accuracy.

The acid of phoſphorus is uſually termed an animal acid. Phoſphorus may be obtained from farinaceous grains, and therefore its origin is probably in the vegetable kingdom; but by far the greateſt quantity is found in urine. If urine be evaporated, ſo as to leave but one third of the original quantity, the ſaline matters it contains begin to cryſtallize as it cools. Theſe ſalts, except one, are nothing more than what has been received with the aliments, and have paſſed through the animal unaltered. One of the firſt that cryſtallizes is the ſalt we have excepted. It is called fuſible ſalt, and conſiſts of the phoſphoric acid combined with volatile alkali. The volatile alkali may be driven off by heat; but the acid is ſo fixed, that it may not only be deprived of the water, by which it was kept in a fluid ſtate, but alſo when thus dried, may be rendered red hot without ſubliming, and may be thereby changed into a

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ſolid and tranſparent matter, which has the appearance of glaſs.

This acid has all the general properties of acids. While hot it corrodes glaſs. But its remarkable property is that by combination with phlogiſton, it forms a ſulphur which is inflammable with a much leſs degree of heat than the common vitriolic ſulphur. Theſe two ſubſtances have the peculiar property of being decompounded by two different kinds of combuſtion. If the end of an iron poker be heated red hot, there will be a certain part of it, at a little diſtance from the ignited end, which will be juſt hot enough to melt brimſtone, and cauſe it to ſmoke, without burſting into its uſual blue flame. Yet this apparent ſmoke is an actual luminous flame, as may be proved by repeating the experiment in the dark; and if the ignited part of the iron be touched with the ſulphur, the ſtrong and ardent flame may be produced at the ſame time, by which the difference may more ſenſibly be obſerved. The faint, or, as it may be termed, the phoſphoreal flame, may be produced in common ſulphur by an iron not much hotter than the hand

hand can bear, and is incapable of ſetting fire to the lighteſt flax. It may even be ſuffered againſt the palm of the hand without inconvenience; in which caſe, the flame is deflected much in the ſame manner as the flame of a candle againſt the ceiling of a room.

Phoſphorus is ſo inflammable, that a very ſlight friction is ſufficient to cauſe the moſt violent combuſtion. The phoſphoreal flame is produced in the open air by a heat conſiderably leſs than that of freezing; conſequently it always ſmokes, and is continually decompoſing, by the eſcape of its phlogiſton, unleſs this ſlow combuſtion be prevented, by keeping it conſtantly immerſed in water.

If urine be boiled to the conſiſtence of an extract, and afterwards ſubmitted to diſtillation, all the volatile products come over firſt, and at length, by a continuation of the utmoſt violence of fire, the phoſphoric acid combines with the phlogiſton of part of the coaly reſidue, and paſſes over in the form of luminous fumes, which, when condenſed by water in the receiver, are the phoſphorus.

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But this proceſs is very tedious and laborious. It is therefore uſual to make it by previouſly mixing a quantity of the extract of urine, with a quantity of plumbum corneum, and a little powdered charcoal, over the fire, till by evaporation the whole is converted into a black powder. Plumbum corneum is a ſaline combination of the marine acid with the calx of lead, and is perhaps of no uſe in this operation. This black powder is ſubmitted to diſtillation by a gradual heat, and the fire is increaſed till the retort is red, and nothing comes over. The receiver is then changed, and a new one being adapted, half filled with water, the fire is raiſed till the retort is brought to a white heat. The phoſphorus paſſes over in vapors, and manifeſts itſelf by the light which ſpreads through the inſide of the receiver, and which iſſues through the little hole made in its body. When the operation is finiſhed, the veſſels are ſuffered to cool during forty-eight hours. At the bottom of the receiver is found a black coaly matter, which contains the phoſphorus. A ſecond diſtillation with a moderate heat rectifies this phoſphorus:

water

water being put in the receiver, to prevent its burning as it comes over. The phoſphorus in this laſt ſtate, is of a pure yellow colour, and being almoſt as fuſible as ſuet, is caſt into ſticks, by putting it with water into ſmall glaſs tubes, which being immerſed in warm water, the phoſphorus melts, and runs into a body at the lower end.

CHAP.

CHAP. VI.

Of Alkalis.

ALKALIS are either fixed or volatile, and there are two kinds of fixed alkali, namely, vegetable and mineral, or, as ſome call it, foſſil. The affinities of alkalis to acids are ſo great, that they are almoſt always found combined with them. Thus, the vegetable alkali is found combined with an acid in tartar, and in nitre, and the mineral alkali is the baſis of ſea-ſalt. The volatile alkali is uſually combined with the marine acid, forming ſal ammoniac.

The vegetable and mineral alkalis being exceedingly fixed, and in general combined with fixed acids, it is evident that they cannot be obtained alone by the common chemical methods. The acid of common ſalt, for example, cannot be made to quit its baſe of mineral alkali, but by combining that baſe with an acid, and to which it has a ſtronger affinity;

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ſo that the alkali muſt always remain in a combined ſtate. The only method of decompounding theſe ſalts, which are compoſed of an acid and an alkali, is that of rendering the acid volatile; but we are not well acquainted with the means of doing this. Thus, if common nitre be made red hot, and charcoal be added, the acid of the nitre combines with the phlogiſton of the charcoal, and is diſperſed by a rapid inflammation: and at length the vegetable alkali is left in an uncombined ſtate. Vitriolic ſalts may likewiſe be decompounded upon this principle: but, the affinity of the marine acid with phlogiſton is ſo ſmall, that a ſimilar proceſs has not yet been contrived with ſea-ſalt.

All the fixed alkali in commerce is produced by burning vegetable ſubſtances, and extracting the alkali from their aſhes by means of water. It has been a matter of diſpute, whether the fixed vegetable alkali be not formed by the combuſtion, or whether it pre-exiſted in the vegetable. Both opinions are partly true. For it is evident that fixed vegetable alkali is contained in

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ſubſtances which have never paſſed the fire, as in tartar or nitre; and it is likewiſe as clear, that concrete acids, as they are called, are almoſt entirely changed into alkali by incineration. If tartar be tied up in wet brown-paper, and burnt, it is converted into an almoſt equal quantity of alkali of very conſiderable purity: and univerſally, thoſe vegetables, which contain the moſt eſſential ſalt, furniſh the greateſt quantity of alkali by burning; but if, by decoction, or maceration in water, they be deprived of thoſe acid juices, or if they be changed by putrefaction, very little alkali is obtained from them.

Fixed vegetable alkali is obtained in a pure ſtate by one or more ſolutions in water, and a careful calcination. At every ſolution an earth is precipitated, and it is affirmed, that alkalis may be entirely decompounded by repeated ſolutions and calcination. The vegetable alkali reſembles a white earthy ſubſtance, which may perhaps conſiſt of broken ſmall cryſtals, and is uſually combined with fixed air; but it may be rendered more cauſtic and incapable of

effervescence, by being treated with quicklime, which deprives it of the fixed air. If exposed to the open air it attracts moisture, increases in weight, and becomes fluid. The vegetable alkali obtained by burning tartar is called salt of tartar, and the fluid produced by its deliquescence, is improperly named oil of tartar per deliquium. Many other names have been given to this alkali, according to the mode of procuring it, as fixed-nitre, potash, &c. but these are all entirely of the same nature.

Mineral alkali is said to be found lying on the ground in the island of Teneriffe, and other places; but the only practical method of procuring it in great quantities is by the incineration of marine plants. These plants contain sea-salt, which probably furnishes the alkali, by a conversion similar to that produced in the burning of tartar. These ashes are known in commerce by the name of barilla, or soda; and the alkali, when purified, is in the form of small transparent crystals. It is so far from imbibing the moisture of the atmosphere, that it even loses the water which entered into the composition of its crystals,

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and falls into a powder by expoſure to the air. This weak affinity with water is one of the moſt diſtinctive circumſtances between the mineral and the vegetable alkali. The mineral alkali has a great reſemblance in all its properties to the vegetable alkali, but in general poſſeſſes them in a leſs degree. It cannot cryſtallize when deprived of the fixed air with which it is generally combined.

The uſe of the fixed alkali, both vegetable and mineral, is very great in the arts. It readily combines with all oils, eſpecially when rendered cauſtic by boiling with quicklime, which abſorbs its fixed air. This cauſtic ſolution or lixivium is called lye or ſoap-lees, and is converted into ſoap by the affuſion of a proper quantity of oil, the whole being kept at a very gentle heat, till it is brought to a proper conſiſtence, by the evaporation of the water. Soaps differ very much, according to the quality of the oil made uſe of. Alkaline lye is likewiſe much uſed in the art of dying.

The property of diſſolving earths, and forming that moſt uſeful and beautiful compoſition, called glaſs, conſtitutes one of the prin-

cipal advantages we enjoy from alkalis. A great heat is neceſſary for this operation; for which purpoſe the melting-pots are placed in a large dome-furnace, in which the flame is continually reverberated on them, and is never ſuffered to go out. Common ſalt and nitre, being in part compoſed of alkali, may be offered as additional proofs of the benefits which ariſe to us by means of this ſubſtance.

The volatile alkali is procured by decompoſition from all animal, and ſome vegetable, ſubſtances, and is likewiſe diſengaged from theſe matters by putrefaction. It ſeems to be the fixed alkali, altered and volatilized by phlogiſton.

There are many chemical proceſſes in which volatile alkali is produced from ſubſtances, in which it did not exiſt before; yet, that it exiſts ready formed in animal ſubſtances, ſeems probable, becauſe they all give out a ſmell of the volatile alkali when fixed alkali is applied to them. Thus, the fuſible ſalt, which conſiſts of the phoſphoric acid united with volatile alkali, exiſts ready formed in urine, whether putrified or not, and the alkali may be diſengaged by throwing in a ſuffi-

a ſufficient quantity of fixed alkali. This, by its greater affinity, combines with the phoſphoric acid, and the detachment of the volatile alkali is immediately perceived by a ſtrong pungent ſmell. And this ſmell is as inſtantly deſtroyed, by throwing in an acid, which fixes the volatile alkali again, by combining with it, and forming a neutral ſalt. But there is no doubt but that in many inſtances volatile alkali is not merely diſengaged, but produced by putrefaction.

The volatile alkali, which is met with in commerce, is obtained from ſal ammoniac, which, as we have obſerved, is a combination of this alkali with the marine acid. Sal ammoniac is found ready ſublimed in the neighbourhood of volcanos; but the quantity is too ſmall to furniſh the demands of artiſts. The great ſupply is from Egypt, where it is obtained by ſublimation, in an impure ſtate, from the ſoot of the dung of camels, which is the common fuel of that country. It is purified with us, by ſolution in water, filtration, and cryſtallization; and may be ſublimed a ſecond time, if thought neceſſary; for the union between the volatile alkali and marine

acid is ſuch, that they cannot be ſeparated by mere heat, without the help of an intermediate ſubſtance.

Volatile alkali may be procured from ſal ammoniac by diſtillation, if a fixed ſubſtance be added, which can combine with the marine acid. Fixed alkali, calcareous earth, or metallic calces, may be employed for this purpoſe. But the volatile alkali cannot be procured in an abſolutely detached ſtate: it is always combined either with water or fixed air; and if the intermediate ſubſtance be incapable of furniſhing either of theſe, as is the caſe with freſh hot quicklime, the decompoſition does not take place. This ſerves to account for a difficulty which has been ſtarted concerning theſe decompoſitions. The volatile alkali has, very nearly, if not quite, as great an affinity with its acid baſe as quick-lime, and a much greater than any metallic ſubſtance, as is evident by its precipitating them from their ſolutions: how then does it happen, that it is diſengaged by theſe ſubſtances? The anſwer is, that though the attraction between the volatile alkali and marine acid is ſo great, that inſtead of being ſeparated, they are both ſublimed together, yet, the addition of a third

third fixed ſubſtance, which has an affinity with the marine acid, may ſo far weaken that attraction, as to render the ſeparation by heat poſſible. Or, if this be not thought ſufficient, the probability of a double affinity taking place in the preſent inſtance is very great. Mild calcareous earth, for example, is added to ſal ammoniac, and the whole ſubmitted to diſtillation. The calcareous earth attracts the marine acid of the ſal ammoniac, which has therefore a tendency to be decompoſed on that account: and the volatile alkali being attracted by the fixed air of the quicklime, combines leſs ſtrongly with its baſe than before. If the ſum of theſe two attractions be greater than that which unites the alkali with its acid, a decompoſition muſt take place, though neither of them ſingly could have effected it. The volatile alkali will conſequently paſs over in a combined ſtate with fixed air, and the marine acid will remain, forming a ſalt with the calcareous earth. A ſimilar effect will follow if the calcareous earth be cauſtic, but containing water, as is the caſe with ſlaked lime, except that the volatile alkali will then be cauſtic, and in a fluid ſtate.

And if lime, containing neither water nor fixed air, be uſed, no decompoſition will take place. But after all, this ſubject has its difficulties.

Volatile alkali differs according to the ſubſtances from which it was procured: but theſe differences are owing to its not being ſufficiently purified. But if it be formed into ſal ammoniac, by applying the marine acid, and afterwards recovered, it is univerſally ſimilar. There is therefore but one ſort of volatile alkali.

All the common properties of alkalis are found in this ſubſtance, excepting ſuch as depend upon fixity, which it wants. Its affinities are weaker than thoſe of fixed alkali. If ſal ammoniac be treated with nitre in a crucible, the nitre inflames and detonates to a certain degree. As the marine acid of ſal ammoniac cannot be ſuppoſed to afford the phlogiſton, it muſt be furniſhed by the volatile alkali. This is an additional cauſe for believing that the volatile alkali contains a greater quantity of phlogiſton than the fixed alkali.

The volatile alkali is uſed as a ſtimulant in fainting fits. With particular management

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it may be formed into a ſaponaceous, compound with oil of amber, or other oils, which being diffuſed in ardent ſpirits, forms that milky liquor called eau de luce. This liquor, externally applied, is ſaid to be a ſpecific for the bite of vipers.

CHAP. VII.

Of compound Bodies; and particularly thoſe which are inflammable.

WE have finiſhed our account of ſimple bodies, in which we have been under the neceſſity of frequently deſcribing and adverting to the properties of the compounds which are produced by their reſpective combinations. This anticipation, which the nature of the ſubject rendered indiſpenſable, will conduce much to the eaſy underſtanding of the nature of the ſubſtances we are about to treat of.

All bodies may be arranged under two general heads; namely, inflammable and uninflammable. The firſt claſs conſiſts of ſuch as poſſeſs the principle of inflammability to ſuch

a degree, that they may be decompounded by the act of combuſtion. Theſe are ardent ſpirit, ether, oils, reſins, ſulphurs, metals, coal, and have no general term by which they may be denoted. The latter claſs, conſiſting of combinations of water, earth, acids, and alkalis, and if they poſſeſs phlogiſton, being united with it in ſuch a manner as to be incombuſtible, may be properly enough denoted under the general name of ſalts.

Here it is to be noted, that we ſpeak of bodies, which, though capable of chemical decompoſition, are yet very ſimple. Even in theſe, the limits of the two claſſes approach by ſuch inſenſible gradations, that it is difficult to draw the diſcriminating line: but in more compounded ſubſtances there is hardly any particular ſpecimen which does not conſiſt of inflammable parts united with others of a ſaline nature.

Ardent ſpirit, or, as it is uſually called, ſpirit of wine, becauſe it is obtained by means of the vinous fermentation, is unalterable by diſtillation, when it is ſufficiently pure. It is very volatile and inflammable, and burns without producing any ſmoke or coal: if it be

be burned in a tubulated retort, to which a large receiver is adapted, the condenſed vapors are found to be very pure water. It ſeems therefore proper to conclude, that ſpirit of wine is pure phlogiſton, combined with water.

If ardent ſpirit be added to concentrated vitriolic acid, and the mixture gently ſhaken, they unite with a boiling heat. By a careful diſtillation, the firſt product which paſſes over is a very dephlegmated ſpirit of wine; next an exceeding volatile fluid, called ether, which runs in ſtreaks down the ſides of the receiver; and, laſtly, an oil, improperly called ſweet oil of vitriol. A reſinous coal remains in the retort. The riſing of the oil is perceived by the ſulphureous ſmell which iſſues from the ſmall hole in the receiver; at which time, in order to preſerve the ether, the receiver is removed. The ether is afterwards ſeparated from the ſpirit by a ſecond diſtillation, with a very gentle heat, in which, on account of its greater volatility, it riſes, and leaves the ſpirit in the retort.

Similar

Similar proceſſes may be made by mixing ſpirit of wine with the other acids; but this is the eaſieſt, and the moſt in uſe.

Oil is an inflammable ſubſtance, inſoluble in water, which, when burned, emits a flame, accompanied with ſmoke; and when diſtilled, leaves a reſiduum of coal. The firſt part of this definition diſtinguiſhes it from ardent ſpirit, which unites with water in all proportions; and the latter part indicates the difference between it and ſulphur, which, though likewiſe inſoluble in water, burns without either ſmoke or reſiduum. Oil is obtained from vegetables and animals, but never from ſubſtances which are indubitably mineral. Bitumens, as petroleum, amber, jet, aſphaltum, and pit-coal, yield an oil; but there are many reaſons to ſuſpect that theſe matters have been produced in their preſent form by time, and the action of the mineral acids on bodies, which in ſome former ages have been in the ſtate of vegetation or animalization. Oils are obtained from vegetables by expreſſion or diſtillation with water. The firſt are called ſweet oils, and the latter eſſential

tial oils. Sweet oils are uſually in an uncombined ſtate in the veſſels of the plant they are expreſſed from; they have very little taſte or ſmell; but eſſential oils are obtained by a decompoſition of the vegetable ſubſtance, and have all the peculiar ſmell of the plant they come from. Theſe latter are exceedingly ſapid, and much more volatile than the other; and, in conſequence of that volatility, are likewiſe more inflammable; for oils cannot be inflamed but in a ſtate of evaporation. In animal ſubſtances there are likewiſe two kinds of oil, namely, the fat, which is contained in an uncombined ſtate in certain detached veſſels, and an oil which is obtained from that gelatinous ſubſtance, or jelly, of which the parts of animals are almoſt entirely formed. This laſt is a true animal oil.

All oils are volatile in a conſiderable degree. The leaſt volatile oil may be raiſed by a heat much leſs than a red heat. They are entirely decompoſed by combuſtion.

If oil be diſtilled without addition, an acid phlegm firſt riſes, and afterwards the oil itſelf, accompanied by an acid, which becomes more and more ſtrong, as the diſtillation advances.

A ſmall

A ſmall quantity of fixed coal remains, which contains earth, phlogiſton, and a minute portion of fixed alkali. If the oil be repeatedly diſtilled, the ſame products are obtained, and the oil becomes more thin and volatile at every diſtillation.

Concentrated acids in general combine with oils, and render them more thick, and approaching to the nature of reſin. Great heat and blackneſs, attended with a ſtrong ſulphureous ſmell, is produced by the admixture of ſtrong vitriolic acid and oil; and the admixture of the nitrous acid with oils produces even accenſion, as has been already remarked.

The variety of oleaginous ſubſtances, and their reſpective products, have not been ſufficiently and accurately attended to. Much remains to be done; but that which has already been done would require too large a detail to be admitted in this place. We ſhall therefore only make a few general obſervations on the nature of the three ſubſtances juſt deſcribed.

In the diſtillation of ether, ſpirit of wine, which was ſhewn to conſiſt of phlogiſton and

water, is converted into an oil, and this oil leaves an earthy reſiduum. The reſiduum muſt then have come from the acid. It is therefore highly probable that oil is compoſed of water, phlogiſton, and acid. Pure ſpirit is entirely ſoluble in water. Ether is partly ſo; and oil is totally inſoluble. Ether then is a kind of intermediate ſubſtance, between ſpirit and oil; and in moſt of the properties by which it differs from ſpirit it approaches to oil. It gives a ſmoke, and leaves a ſlight reſiduum in burning, and has other oleaginous qualities; but, on the hand, it is volatile like ſpirit, and riſes entire in diſtillation. The analyſis of oils ſhews that they contain water, phlogiſton, acid, earth, and a ſmall proportion of alkali. They are decompoſed by diſtillation. A part of the phlogiſton is diſſipated: hence water and acid appear in an uncombined ſtate. The earth and alkali in the reſidue are probably part of the ſame acid, ſtill more decompounded: this is rendered probable, by the formation of oil from ardent ſpirit, juſt mentioned, in which the acid furniſhed an earthy reſiduum. And the diſtilled oil, being deprived of part of its acid, becomes

becomes more volatile and attenuated; that is to ſay, it approaches to the nature of ſpirit. In farther confirmation of this, we find that ſtiff and concrete oils, as ſuet, and wax, afford a greater portion of acid than thin ones; and thin oils may be rendered thick by the addition of an acid. On the whole, ſince the differences between fluid oils, concrete oils, wax, and reſins, conſiſt, in a great meaſure, in the varieties of conſiſtence; and ſince the moſt concrete oils may be attenuated in an almoſt unlimited manner, by repeated diſtillations, we may expect that future experiments will ſhew that theſe ſubſtances, ſeemingly ſo various, are much more ſimilar than has been imagined.

The animal oil obtained from jelly gives no indication of the preſence of an acid, inſtead of which volatile alkali enters into its combination. Spirit of wine, digeſted with ſtrong and dephlegmated alkalis, is converted into an oily or ſaponaceous ſubſtance, without paſſing through an intermediate ethereal ſtate, as is the caſe when it is treated with acids.

Eſſential oils, and their concretions, as balſams and reſins, are ſoluble in ſpirit of wine, but

but fat oils and bitumens are not. Theſe, and the other properties of ſpirit of wine, as a ſolvent, render it exceedingly uſeful in the hands of chemiſts, for making the analyſis of compound bodies by the moiſt way.

We have already taken notice of the formation of ſulphur in the chapter on acids; and ſhall only obſerve in this place, that it is ſoluble in all oils. For this purpoſe, an heat ſufficient to melt the ſulphur muſt be uſed. More ſulphur is held in ſolution by oil when hot than when cold, and conſequently a part is ſeparated from the oil as it cools: this part takes a regular arrangement, if the cooling be gradual. Oils impregnated with ſulphur are called balſams of ſulphur.

When compound ſubſtances, into the compoſition of which earth and phlogiſton enter, are expoſed to heat in cloſe veſſels, as in diſtillation, the volatile parts are all detached and raiſed, and the earth remains combined with the phlogiſton. This combination is called coal, and affords ſome reaſon to ſuſpect that the affinity of phlogiſton to earth is greater than to any more volatile ſubſtance, pure air and nitrous acid only excepted.

Charcoal,

Charcoal, for example, is phlogiſton, combined with the earth of wood; for it burns in the air without ſmoke or moiſture, and leaves an earth: and charcoal cannot be decompoſed unleſs pure air, nitre, or ſome dephlogiſticated earth be preſented to it in a very heated ſtate. And this being the caſe, is an additional reaſon why we cannot expect to obtain phlogiſton in an uncombined ſtate.

CHAP.

CHAP. VIII.

Of Metals. Gold. Silver. Platina.

IF a philoſophical enquirer were to undertake to ſearch into the component parts of natural bodies, it is probable that his attention would be fixed very early upon thoſe hard ſubſtances which contain the metals. Their ſpecific gravity is ſo great, that the moſt ignorant perſon cannot take an ore into his hand without being actuated by a wiſh to know what it is which occaſions its great weight. But the arts originated in times when neceſſity was the immediate inducement to almoſt every action. Leiſure, and a certain independance of manual labour, have given opportunities to men of genius to ſyſtematize and ſpeculate on diſcoveries which accident had produced long before; and metallurgy, which has been practiſed from immemorial time, is now become a rational ſcience.

If the word ore be uſed in its moſt extenſive ſenſe, there are few ſands, clays or mud, which do not contain a ſmall portion of metal; but ores, properly ſo called, are thoſe ſubſtances which contain ſuch a quantity of metal as to give them a remarkable appearance, and to make them worth the miners attention. They are not in general found in any conſiderable quantity on the ſurface of the earth, but are obtained by digging. The cavity thus formed in the earth, on this occaſion, is called a mine.

Metals are very ſeldom found pure. They are either mixed or combined with other ſubſtances. The ſtate of combination is called mineralization. Gold is never mineralized in its ore, but only mixed and diſperſed though the maſs. The other metals are almoſt always in a mineral ſtate, and therefore can ſeldom be extracted from the ore by pounding, waſhing, or ſolution, as gold may. Solid ores are moſt commonly covered with a kind of encruſtation, which mineralogiſts conſider as their matrix. This encruſtation conſiſts for the moſt part of a great number of regularly formed hexagonal cryſtals, ſufficiently hard

hard to ſtrike fire with ſteel. Their ſize, color, and tranſparency, is various in various ores. They are called quartz. Ores are likewiſe often accompanied with a leſs hard ſtone, called ſpar, of a rhomboidal quadrangular figure, and of the nature of gypſum. An attention to theſe and other matrices might perhaps indicate ſome intereſting particulars relative to the earth of metals.

Metals are more frequently mineralized by ſulphur or arſenic than by any other ſubſtance. The art of refining conſiſts in ſeparating theſe ſubſtances from the metal, taking care at the ſame time that the metal ſhall not be deprived of the phlogiſton, or reduced to a calx; for in this laſt ſtate, being much leſs fuſible than otherwiſe, it would remain mixed with the earthy matters of the ore, inſtead of melting into a maſs at the bottom.

Metallic ſubſtances are diſtinguiſhed from all other bodies by their great weight. They are, gold, ſilver, platina; copper, iron, tin, lead; mercury: regulus of antimony, biſmuth, zinc, regulus of cobalt, regulus of arſenic, and nickel. The eight firſt are called metals, of which gold, ſilver, and platina, are

called perfect; copper, iron, tin, and lead, are called imperfect metals; and mercury, on account of its great fusibility, volatility, purity, and other properties, cannot, with propriety, enter into any class. The six last bodies are called semi-metals, because they possess the metallic properties in a less degree than even those metals which are stiled imperfect.

The metallic properties are great specific gravity, fixity, and malleability. Those bodies, which possess all these properties, are called metals. The perfect metals are so termed, because they cannot be deprived of them by mere heat, without addition. The imperfect metals may be very much altered by calcination. And the semi-metals have little or no malleability; besides which, some of them are very volatile, and even combustible, so as to produce an actual strong flame.

Gold is found in a great variety of forms. It is frequently imbedded in quartz, and is found intermixed in larger or less particles among the sands of rivers. These are collected by the natives on the Gold Coast of Guinea, and in Potosi, in South America, and are separated by washing with water, which

riescar

carries off the lighter earth and impurities. The remaining matter is dried, and ground or kneaded with quickſilver, which diſſolves the gold, and by ſhaking in a bag, or otherwiſe, is collected into a maſs, from which the gold may be obtained, by ſtraining through leather, or by fire. The cupel is alſo uſed in the purification of gold. It is a ſhallow diſh, or crucible, in which the matter containing gold is expoſed, together with lead, to the reverberated flames of a furnace. The lead is converted into glaſs, and *vitrifies* every impure metal, or other ſubſtance, which either ſoaks through the cupel, or is blown aſide by large bellows, and leaves the gold in a refined ſtate.

But this proceſs is inſufficient for the ſeparation of the perfect metals from each other. Silver is ſeparated from gold by parting. The operation of parting conſiſts in expoſing the maſs to the action of the nitrous acid, which diſſolves the ſilver, but has no affinity with gold, in its aggregate ſtate: the parted gold is conſequently left in a porous form, which may be eaſily broken.

Platina cannot be ſeparated from gold by parting, on account of the ſimilarity of its

properties to thoſe of gold: but if a mixture of gold and platina be diſſolved in aqua regia, the platina may be precipitated alone in the form of a yellow powder, by the addition of ſal ammoniac; and, on the other hand, if martial vitriol be added inſtead of ſal ammoniac, the gold will be precipitated ſingly. In the refining of this, as well as all the other metals, peculiar contrivances are made uſe of, which are adapted to the ſtate of the ore and the nature of the metal. The detail of theſe circumſtances, though of great importance in practical metallurgy, would be too long for the limits we have preſcribed to this work.

Pure gold poſſeſſes the metallic properties, without the poſſibility of their being deſtroyed by any continuance of heat, human induſtry has yet deviſed. It likewiſe poſſeſſes them in the moſt eminent degree. Gold is thought to be the heavieſt, the moſt unalterably fixed, and the moſt ductile and tenacious body in nature. Its ductility appears by the inſtances alledged concerning gold leaf, at the beginning of this treatiſe. To add to the ſurpriſe which ſuch a ſubtilty or minuteneſs of particles

muſt occaſion, we will again take notice of the gilding ſilver wire to make lace. For this purpoſe it is uſual to gild a cylindrical bar of ſilver ſtrongly, and afterwards draw it into wire, by paſſing it ſucceſſively through holes of different magnitude in plates of iron. By this means the ſurface is prodigiouſly augmented; notwithſtanding which, it ſtill remains gilt, ſo as to preſerve an uniform appearance even when examined by the microſcope. The quantities of gold and ſilver employed, and the dimenſions of the wire are known. With theſe data, it is eaſy to calculate, and from calculation it is proved, that ſixteen ounces of gold, which, if in the form of a cube, would not meaſure one inch and a quarter in its ſide, will completely gild a quantity of ſilver wire, ſufficient to circumſcribe the whole globe of the earth.

The great tenacity of gold is proved by ſuſpending a weight at the end of a wire of a determinate thickneſs, in which ſituation a greater weight is ſupported than any other metal of the ſame thickneſs would ſuſtain. Gold is not hard, is of a bright

yellow colour, and contracts no ruſt by expoſure to air and water. The colour of different ſpecimens of pure gold is not exactly the ſame.

When gold is expoſed to the fire, it ſoon becomes red hot. It is not eaſily melted; but juſt before the fuſion it aſſumes a lively green colour, which continues during the time it remains fluid. Yet it ſuffers no alteration by this means. Several philoſophers have expoſed gold to the utmoſt violence of fire for more than a month, without finding it ſuſtained any loſs or change. However, gold is ſaid to have been vitrified by means of a very large burning lens; but it does not appear that this experiment has ever been made with that caution and accuracy which are neceſſary to put the matter out of doubt.

Gold, while its aggregation is entire, reſiſts the action of the ſtrongeſt chemical menſtruums, either in the dry or the humid way. It is not ſoluble, either by the ſtrongeſt mineral acids, when they are pure, nor by ſulphur, nor by alkalis. Two compound bodies nevertheleſs are powerful ſolvents of gold.

gold. The firſt is a mixture of the nitrous and marine acids, called by chemiſts *aqua regia*, becauſe it diſſolves gold, the king of metals; and the ſecond ſolvent of gold is liver of ſulphur.

The ſolution of gold in aqua regia is very eaſy. A very ſmall quantity of nitrous acid, or even of inflammable matter, added to the marine acid, gives the latter the power of diſſolving gold. Alſo a very ſmall quantity of marine acid, or of any of the ſalts containing it, added to nitrous acid, renders the nitrous acid capable of diſſolving a certain quantity of gold. But experience has ſhewn, that an aqua regia compoſed of four parts of nitrous acid, and one of ſal ammoniac, diſſolves perfectly well a fourth, or even a third part of its weight of gold, according to the ſtrength of the acid. Heat is neceſſary to complete this ſolution, which is of a fine tranſparent yellow.

The power which the nitrous and marine acids acquire by their union, of diſſolving gold, which neither of them have ſeparately, is one of the moſt remarkable facts in chemiſtry.

miſtry. If we may judge of the perfect metals from the phenomena which the imperfect afford, all metals are compoſed of phlogiſton united with certain earths. In ſpeaking of the nitrous and marine acids, we obſerved that the affinity of the nitrous acid to phlogiſton is ſuch, that it appears to hold bodies in ſolution merely by that medium: and it was likewiſe noticed, that the marine acid, though poſſeſſed of very little affinity to phlogiſton, was more capable of diſſolving metallic calces or earths than other acids were. This being the caſe, a probable theory may be given of the appearance before us. The earth of gold and its phlogiſton adhere together with a prodigious force, as is evident from its property of reſiſting calcination. The affinity of nitrous acid to the phlogiſton is likewiſe exceedingly great; but not ſufficiently ſo to break and deſtroy the aggregation of the gold, or, in other words, to diſſolve it. Its action, therefore, only diminiſhes the force by which that aggregation is preſerved. The ſame argument may be urged reſpecting the affinity between the marine acid and the

earth

earth of gold. Now, though the ſingle action of the nitrous acid may be inſufficient to detach the phlogiſton from the earth, and the ſingle action of the marine acid may be inſufficient to detach the earth from the phlogiſton; yet it is very probable, that their united efforts may be capable of producing that diviſion, or partial decompoſition, in which ſolution conſiſts.

Liver of ſulphur ſeems to act upon gold nearly on a ſimilar principle. If gold leaf be mixed with melted liver of ſulphur, it becomes entirely diſſolved, and if the liver of ſulphur be then diſſolved in water, the gold will paſs with the ſolution through a filter. In this inſtance the vitriolic acid of the ſulphur ſeems to attack the phlogiſton of the gold, while the alkali combines with its earth. And thus a ſolution is made, which could not have been ſingly effected either by the ſulphur or the alkali.

Solution conſidered ſimply, is an union of the integrant parts of one body with the integrant parts of another. It is a combination which ſeems to take place by the mechanical diviſion, without any real decompoſition

compoſition of the bodies: and therefore, nothing more is neceſſary for it to take place, than that the mutual affinity of the bodies be ſufficiently ſtrong to overcome the attraction by which the integrant parts are united, and form an aggregate. For inſtance, the nitrous acid attracts the phlogiſton of iron ſufficiently to deſtroy the aggregation of the metal, and to reduce it into parts, ſo fine, that they intermix without deſtroying the fluidity of the acid; but its affinity is not ſo ſtrong as to deſtroy the attraction between the earth of iron and its phlogiſton: and therefore the earth remains ſuſpended by the medium of the phlogiſton. This is ſolution; and in this no real decompoſition takes place. But with tin it is otherwiſe. The nitrous acid unites with the phlogiſton of this metal ſo ſtrongly, as not only to deſtroy the aggregation of its parts, but likewiſe to detach it almoſt entirely from the earth. Conſequently this laſt is for the greateſt part precipitated in the form of a very fixed calx. This is not ſolution, but decompoſition.

By a proper conſideration of this, it may eaſily be underſtood, that there may be many menſtruums

menſtruums which poſſeſs a ſufficient affinity with a given body, or ſome of its principles, to hold it in ſolution, if preſented in a ſtate of extreme diviſion, though they may be incapable of acting upon it in an aggregate form. For it is the force of aggregation which is the antagoniſt to the diſſolving power of a menſtruum. Many affinities have been diſcovered, by preſenting bodies to each other in the form of very ſubtile powder, or of ſteam, which could not have been manifeſted any other way; and there is reaſon to imagine, that there are no two bodies but whoſe particles, if ſufficiently detached, would exhibit a mutual affinity. Thus, gold, when precipitated from aqua regia, by means of an alkali, or any other ſubſtance which has a ſtronger affinity to the acid, is in a ſtate of extreme diviſion, and may then be diſſolved in any acid, and even by alkalis, with proper management.

Chemical phenomena are very frequently fallacious; and it requires much care and unprejudiced attention to reaſon properly concerning them. Precipitations, for example,

are uſually made by the addition of ſome ſubſtance which engages the menſtruum with a greater affinity than the matter already diſſolved. But this is not always the caſe. The calces of metals are precipitated from the nitrous acid by the affuſion of the marine acid, not becauſe this latter acid unites with the former, but becauſe it combines with the calces, to which it has a greater affinity than the nitrous acid. This combination, therefore, falls to the bottom neither in the form of a calx, nor a metal, but of a ſalt. And in like manner, gold may be precipitated from aqua regia, much more readily by the volatile than by the fixed alkali; notwithſtanding the affinity of the latter to the acid is much greater than the former. But both the cauſes of precipitation are united in the uſe of the volatile alkali. The volatile alkali not only tends to precipitate the gold, by ſaturating the acid, but likewiſe by combining the metal, and forming a ſaline matter, which is conſiderably heavier than the original quantity of gold. This precipitate is yellow, and is named *aurum fulminans*, from its ſingular property of exploding with great violence and

and noiſe, if expoſed to a very moderate degree of heat.

The uſes of gold, and the ideal value which the conſent of mankind has ſtamped upon it, are too well known to need any enumeration. It is commonly mixed and allayed with copper, for the purpoſe of giving it a ſufficient degree of hardneſs; and in this ſtate the proportion of pure gold, or the fineneſs of any maſs is expreſſed by imagining the maſs to be divided into twenty-four equal parts, which are called carrats, and mentioning the proportional quantity of pure gold. Thus a maſs containing twenty-two parts of gold, and the reſt copper, is called gold of twenty-two carrats fine, and the like is ſaid of other proportions. This proportion, namely, of twenty-two carrats, is likewiſe called ſtandard gold, becauſe it is the ſtandard of the fineneſs of the Engliſh gold coin.

In fixity and ductility, ſilver takes the next place to gold. It is mineralized by arſenic and ſulphur, and aſſumes various appearances, according to the manner and proportion of the combination. The methods of refining

it are chiefly founded on its indeſtructibility by fire. It is ſometimes found in a pure or virgin ſtate.

Pure ſilver is of a ſhining white colour, and ſomewhat harder than gold. It appears to be as fixed and indeſtructible as gold, but its ſpecific gravity and ductility are much leſs, as is likewiſe its tenacity. It is not liable to ruſt, but is very apt to aſſume a black colour or tarniſh, from phlogiſtic vapours. This property of attaching to itſelf a greater proportion of phlogiſton than is neceſſary to its metallic ſtate, is not peculiar to ſilver, but is poſſeſſed by it in a greater degree than by any other metal.

Silver is not eaſily diſſolved in its aggregate form by any acid but the nitrous; though with proper management it may be made to unite directly with the vitriolic or marine acids. But the readieſt method of forming ſaline combinations of ſilver with acids, is to precipitate it from the nitrous acid, by the affuſion of the acid with which it is intended to be combined.

Platina is a metal, which has not been attended to till about the middle of the preſent

ſent century. It is found in angular grains in Spaniſh South America, and is very ſcarce in Europe. The colour of the grains is metallic, white, lucid, not very brilliant, but intermediate between the white of ſilver and the grey of iron. They are ſmooth, and are nearly as hard as iron; but they have ſcarcely any ductility. Some of them may be flattened on an anvil, while others are broken into ſmall pieces. The ſpecific gravity of platina, in its crude ſtate, is nearly equal to that of gold.

Platina, like pure gold and ſilver, is free from all ſmell or taſte. It is not ſuſceptible of ruſt, and is indeſtructible by the moſt violent and long continued heat. But the moſt peculiar and diſtinguiſhing property of this metal is its infuſibility by the moſt intenſe heat of ordinary fires. Yet a ſmall quantity has been fuſed, and rendered more malleable, by expoſing it to the focus of a large burning-glaſs.

Neither ſulphur, nor the pure acids have any action on platina; but it may be diſſolved in aqua regia, and alſo by liver of ſulphur.

The action of theſe matters on platina is however leſs than on gold. The ſolution in aqua regia is of a much more deep and intenſe yellow than that of gold, and it may be precipitated, either by the volatile or fixed vegetable alkalis. But it is remarkable, that the mineral alkali does not produce the leaſt precipitation, nor ſo much as render the liquor turbid, even though it be added in ſufficient quantity to ſaturate the acid. None of the precipitates of platina have the property of fulminating.

Notwithſtanding the extreme difficulty of fuſing platina in its natural form, the precipitate obtained by adding ſal ammoniac to the ſolution in aqua regia may be fuſed without addition, by the intenſe heat of a forge-furnace, urged by double bellows. The fuſion in this caſe is very imperfect, but the metal is rendered nearly as malleable as ſilver, and when well hammered, is the heavieſt body in nature, being ſpecifically to water, as 20170 to 1000; which is more than one fiftieth part heavier than gold.

All

All the other metals may be united with platina, and by that union acquire ſeveral valuable properties: but the prohibition of the Spaniſh miniſtry againſt exporting this metal from America, prevents its being applied to any uſe.

CHAP. IX.

Of the imperfect Metals. Copper. Iron. Tin. Lead.

NEXT to the perfect metals, the moſt fixed and moſt malleable is copper. It is almoſt always met with in a mineralized ſtate, and its ores may in general be known by ſpots of verdigriſe interſperſed on their ſurface. Some copper ores are rich in ſilver.

Pure copper is of a red ſhining colour. It is very hard, elaſtic and ſonorous, and is affected by the combined actions of air and water, from whence it is much diſpoſed to ruſt: it emits a very peculiar and diſagreeable ſmell when rubbed, and its taſte is equally unpleaſant. Every menſtruum can corrode and diſſolve this metal.

Copper is eaſily calcined or deprived of its phlogiſton, if ignited or melted with acceſs of air. If one end of a poliſhed piece of copper be heated, ſeveral ſucceſſive ar-

rangements

rangements of colours will be produced on its ſurface, ſimilar to thoſe of the thin plates mentioned in the optical part of this work. This phenomenon is common to all the imperfect metals, and ſeems to ariſe from the progreſſive calcination of the parts of the ſurface. For a certain part of the ſurface is calcined in a given time, and the thickneſs of that part is determined by the degree of heat: and ſince the degree of heat diminiſhes as the diſtance from the heated end increaſes, ſo alſo muſt the layer of calcined matter diminiſh in thickneſs. The ſeries of colours muſt therefore be exhibited by reflection, according to the ſeveral thickneſſes *.

By a ſufficient degree of heat, the calces of copper may be converted into glaſs of a reddiſh brown colour. The calces of this, and indeed of all the imperfect metals, may be reduced to their metallic form, by being heated with phlogiſtic matters; but the reduction is the more difficult in proportion as the calces are more completely dephlogiſticated.

* Book II. Section I. Chap. VII.

The ſalts and precipitates formed by the ſolution of copper, are of great uſe in the arts. Such are blue vitriol and verdigriſe and the precipitates which are obtained by adding calcareous earth, or alkalis, to a ſolution of copper in the nitrous acid.

It is a general effect with ſolutions of the imperfect metals in acids, that if a precipitate be obtained by the addition of an alkali or an earth, that precipitate is a calx of the metal previouſly diſſolved. But if another metal, whoſe affinity with the menſtruum is greater than that of the metal previouſly diſſolved, be added inſtead of the alkali, this laſt will be precipitated in its metallic form. Or, laſtly, if the metal be precipitated by the affuſion of another acid, whoſe affinity to the metal, or its earthy principle, be greater than that of the menſtruum in which the ſolution was made, the precipitate will be a ſalt. The natural inference from this is, that metals are moſt commonly held in ſolution by the medium of their phlogiſton, and cannot be precipitated in their metallic ſtate, except by the addition of another body, which is capable of

of ſupplying the precipitating calces with phlogiſton. Such bodies are metals.

Iron is the next metal in fixity to copper. Moſt of the minerals called iron ores, have an earthy, ruſty, yellowiſh, or browniſh appearance. This metal is by far the moſt abundant of any. There is ſcarcely an earth, a ſand, a chalk, a clay, a vitrifiable, or calcinable ſtone, or even the aſhes of any ſubſtance, which does not contain an earth convertible into iron. The loadſtone is an ore of iron.

Iron is a metal of a white lucid greyiſh colour. It is the hardeſt and moſt elaſtic of all metals, and, except platina, the moſt difficult to be fuſed. Its tenacity is likewiſe greater than that of any other metal except gold.

That which is generally called iron is not ſufficiently metallized, on account of the difficulty of bringing a large maſs into a good fuſion. In the forges or iron-works, the hammer is in ſome meaſure made to ſupply this defect. For by repeated ignition and hammering, the iron is, as it were, kneaded; and the earthy parts worked out to its ſurface,

while the metallic parts are welded or united together. But the pureſt iron is that which is known by the name of ſteel. In this all the properties of iron are found in the moſt eminent degree. It is obtained by ſupplying the beſt common iron with that phlogiſton, which is wanting to completely metallize its earthy part. Steel is made by fuſing a quantity of iron in contact with charcoal, or even without fuſion, by a proceſs called cementation. The cement is formed of two parts of charcoal, and one of wood-aſhes, well powdered and mixed together. The bars of iron are placed vertically in a cylindrical crucible, and are ſurrounded with the cement, ſo that they may be an inch diſtant from each other, and from the ſides and ends of the crucible. In this ſituation the cover of the crucible is carefully luted on, and the whole expoſed to an equal red heat for about eight or ten hours; at the end of which time, the iron is found to be converted into ſteel. Yet as there may be impurities in the bars of ſome other kind than the unmetallized earth, this ſteel will be rendered purer, and of a more even texture, if it be afterwards fuſed.

The

This remarkable property, of becoming metallized without fuſion, is peculiar to the earth of iron.

Iron is the only metal that is hard enough to ſtrike fire with vitrifiable ſtones, or with itſelf. It is a combuſtible ſubſtance, and when exceedingly heated, burns in a ſenſible manner. A number of vivid and ſhining ſparks ſhoot out from it, which burn with a kind of decrepitation, and at length it is converted into a calx. But though iron may be eaſily calcined, it is very difficult to deprive the calx of the laſt portions of phlogiſton.

A very remarkable phenomenon appears in the precipitation of iron from its ſolvent, by the addition of an alkali which has been previouſly calcined with bullocks blood, or ſome other phlogiſtic matter. The precipitate is of a fine blue, is inſoluble in acids, and is known by the name of Pruſſian blue.

The theory of pruſſian blue is embarraſſed with many difficulties. There can be little doubt but that the alkali obtains or becomes combined

combined with phlogiſton, by calcination with inflammable ſubſtances. In proportion as this phlogiſtication is more perfect, ſo much the more does the alkali appear to be deprived of its peculiar properties; and if ſaturated with phlogiſton, it loſes its power of combining with, and neutralizing, acids. But if the phlogiſticated alkali be added to an acid already combined with iron, the united attractions of the acid to the alkali, and of the iron to the phlogiſton, occaſion a decompoſition, which neither could ſingly have effected. The acid unites with the alkali, and forms a ſalt in ſolution of exactly the ſame nature as would have been produced by the addition of a pure alkali, while the phlogiſton of the alkali unites with the iron, and forms the blue precipitate. If the alkali uſed for this purpoſe be not well phlogiſticated, as is ſeldom the caſe, the precipitate is impure, and green, conſiſting partly of pruſſian blue, and partly of an ochreous calx: this laſt may be diſſolved by the affuſion of marine acid on the precipitate, after previouſly ſeparating it from the menſtruum by filtration.

Pruſſian

Pruſſian blue then is iron, ſuperabundantly phlogiſticated. A ſlight calcination expels the exceſs of phlogiſton, and reſtores it to the ſtate of iron: likewiſe a ſolution of very pure alkali being poured on pruſſian blue, deprives it of its color, and reduces it to an ochre; the alkali at the ſame time becoming completely phlogiſticated, if the quantity of pruſſian blue be ſufficient. Here it is obſervable, that the affinity of the alkali is greater than that of the iron to the coloring matter of the pruſſian blue, ſince it attracts it from the latter; and that iron can only become pruſſian blue when there is an acid preſent, which, by attaching itſelf to the alkali, weakens its attraction to the phlogiſton.

But the great difficulty of this apparently conſiſtent and obvious theory is, that if phlogiſton be the medium of affinity between acids and metals, and even alkalis, as there is great reaſon to imagine, it is ſtrange that an exceſs of phlogiſton ſhould deſtroy that affinity. If this be true, there muſt be a certain maximum of affinity between acids and metals, for example, iron, which will depend on a preciſe proportion of phlogiſton in the latter,

and

and will be diminiſhed either by adding to, or ſubtracting from that proportion. Pruſſian blue, for inſtance, is inſoluble in acids: a ſlight calcination renders it ſoluble; a greater calcination renders it leſs ſoluble. The metallic ſtate then is a kind of medium between a calx and a ſuperphlogiſticated combination: from which it ſeems to follow, that an alkali, phlogiſticated to a certain degree, ought to precipitate iron in its metallic ſtate; which, nevertheleſs, does not happen. Notwithſtanding theſe objections, it is probable that the theory is true, and, if well underſtood, would perhaps lead to diſcoveries of importance: but in order to promote that caution, which cannot be too much inculcated in philoſophical matters, we have choſen to ſpeak in an indeterminate manner.

All vegetable aſtringent ſubſtances, as galls, pomegranate rind, &c. precipitate iron from its ſolvents in a black powder, or mud. This black powder ſeems to be formed by a proceſs ſomething analogous to that which obtains in making pruſſian blue; but it differs from this laſt ſubſtance in ſeveral reſpects, particularly in that of being ſoluble in acids. If gum be added,

added, together with galls, to the ſolution of iron, the precipitate is formed, but is kept ſuſpended in the liquid by the mucilaginous quality of the gum; conſtituting that black fluid, which is known by the name of ink.

The affinity of iron to ſulphur is very great, and exceeds that of any other metal to that ſubſtance. It is therefore ſucceſsfully employed as a medium in the depuration of ſeveral ſulphureous ores. Iron is conſiderably more fuſible when combined with ſulphur than when alone. If a bar of iron, heated to a white heat, be applied to a roll of ſulphur, a combination takes place; and the melted matter, which falls, is a kind of pyrites, formed of both ſubſtances. This experiment ought to be performed over a pail of water, that the melted matter being immediately extinguiſhed, may not incommode the operator with its fumes.

The decompoſition and ſpontaneous accenſion of ferruginous pyrites have already been mentioned. Theſe effects are produced but ſlowly, on account of the ſmall proportion of iron, and a quantity of earth, which enters into

into the compoſition of theſe natural bodies. But if equal weights of iron-filings, and powdered ſulphur, to the quantity of twelve pounds or more, be kneaded together into a paſte with water, the mixture, in a few hours, will ſwell, become hot, melt, emit vapors, and take fire. The rationale of this has been ſufficiently explained in ſpeaking of the vitriolic acid.

Iron is a very deſtructible metal. It is ſtrongly acted upon by moſt menſtruums, and in ſome degree by all: whence it is very ſubject to ruſt.

But the moſt uncommon and peculiar property, which diſtinguiſhes this uſeful metal from every other ſubſtance on earth, is the attractive or repulſive force which one piece of iron exerts on another at a very ſenſible diſtance. Several of the ores of iron poſſeſs this property, and are called loadſtones, or magnets, and the property is called magnetiſm. Iron which has been extracted from the ore by art is not ſenſibly magnetical, but may be rendered ſo by rubbing, filing, electrifying, contact with a magnetical ſubſtance, or by long remaining in one poſition. This attraction

attraction and repulſion being the only permanent power of the kind which comes under the immediate cognizance of the ſenſes, may, perhaps, in ſome future time, ſerve as a clue to direct the purſuit and diſcovery of the cauſes of the attractions of gravity, the attractions and repulſions of coheſion, electricity, &c. and is of ſuch importance both to philoſophy and the practical ſciences of navigation and geography, in their moſt extenſive ſenſe, that it will be proper to treat of it in a ſeparate chapter.

The great hardneſs of iron renders it extremely uſeful for the conſtruction of all cutting tools. If heated, and plunged ſuddenly in water, it becomes very hard and brittle. This operation is called tempering, and is ſuch, that ſteel is often made ſufficiently hard to cut glaſs.

Tin is ſeldom found in a virgin or pure ſtate. Its ores are various; but the richeſt is a ſtone of a blackiſh brown color, and is much heavier than ores in general are. The cauſe of this is, that arſenic is the ſubſtance with which tin is combined in its mineral ſtate; whereas other metals are uſually mineralized

ralized by ſulphur, which is a much lighter body than arſenic.

Tin is of a white color, reſembling ſilver, though leſs beautiful. It is the lighteſt of all metals, and, except lead, the ſofteſt and leaſt elaſtic. Leſs heat is required to melt tin than any other metal, and it may be eaſily reduced to a calx, which is very refractory, but may, however, be vitrified by a violent heat in particular circumſtances. This metal may be attacked and diſſolved by all the acids; and the phenomena it affords are various and intereſting. Nitrous acid attacks tin with great violence, but ſeems to unite very little, if at all, to its earthy part; this latter, therefore, is continually precipitated in the form of a white calx, which is very difficult of reduction. When tin is diſſolved in the vitriolic acid, ſulphureous vapors are emitted, and ſmall particles of black inflammable ſulphur are obſerved ſwimming in the menſtruum. Theſe circumſtances, added to the readineſs with which tin may be calcined by fire, ſeem to indicate that the adheſion between its phlogiſton and earth is very weak.

Tin is not much ſubject to ruſt, but contracts a ſuperficial tarniſh, from the action of the atmoſphere, which does not enter deeply into its ſubſtance. It is therefore advantageouſly uſed in tinning copper utenſils, and covering the ſurfaces of thoſe thin plates of iron which are commonly called tin. The compoſition called pewter conſiſts of tin, allayed with a ſmall proportion of copper, biſmuth, lead, and zinc.

All metals may, by fuſion, be combined with tin, and in all proportions. It renders them much more brittle and ſonorous. The ſpeculums of reflecting teleſcopes are made of a mixture of tin and copper. If tin be added to mercury, a ſolution, or perhaps mixture, takes place, and the mercury becomes leſs fluid in proportion as the quantity of tin is greater. If the proportion of tin be very great, a kind of paſte is formed, called amalgama. The greater part of the mercury, which is thus united with tin, may be ſeparated by ſtraining through a piece of leather; which ſeems to indicate, that no real ſolution takes place. From the ſpecific gravity of the amalgama, there is reaſon to conclude,

that the integrant parts of tin are at leaſt of as great ſpecific gravity as thoſe of mercury.

The ſilvering of looking-glaſſes is an amalgama of this kind. For, quickſilver being diffuſed on a leaf of tin-foil, the glaſs is ſlipped upon the ſurface, and, by means of weights, is preſſed down ſo as to exclude the ſuperfluous quickſilver. The amalgama adheres to the glaſs, and in a ſhort time is ſufficiently hard to be handled and applied to uſe.

Lead is almoſt always found in a mineralized ſtate. In general it is mineralized by ſulphur, and appears of a dark white metallic color, internally compoſed of cubes of different ſizes applied to each other, but not adherent. The ores of lead almoſt always contain ſilver.

Lead is of a blueiſh white, and has leſs hardneſs, ductility, tenacity, or elaſticity, than any other metal. Its weight is conſiderable, being the heavieſt body in nature, except gold, platina, and mercury. It is nearly as fuſible and calcinable as tin, but its calces are not ſo refractory. For they cannot be made to part with the laſt portions of phlogiſton, and are very eaſily revived and converted again into lead. In the calcination of lead by a moderate

moderate fire, the calx is firſt grey; then yellow, called maſſicot; then red, called minium, or red-lead: if the fire be increaſed, the red-lead is converted into a pale red or yellow vitrified ſubſtance, called litharge; and if it be ſtill more urged, a true vitrification takes place, and the litharge becomes glaſs of lead. Glaſs of lead is ſo fluid and active, that it paſſes thro' the moſt compact crucibles. Theſe ſubſtances are all of great uſe in the arts.

Lead is ſoluble by all acids, and preſents nearly the ſame phenomena as ſilver. It is ſubject to ruſt by expoſure to the air, but much leſs ſo than either iron or copper. Sheet-lead, expoſed to the vapors of vinegar, becomes covered with a ruſt of a beautiful white color, called ceruſe, or white-lead.

The purpoſes to which lead is applied are very numerous. Its application to the purifying the perfect metals by the cupel has already been explained. The eaſe with which its calx may be fuſed renders it very advantageous as a flux in the preparation of enamels. It enters into the compoſition of moſt fine glaſs, and is the baſis of the glazing of all the better kinds of pottery.

CHAP. X.

Of Mercury, or Quickſilver.

MERCURY is frequently found pure, but much oftener combined with ſulphur, in the form of red maſſes, compoſed of needle-like parallel ſtriæ. This maſs is called native cinnabar. There is another ore of mercury, of a blackiſh grey color, of a glaſſy texture, and brittle, which contains a ſmall proportion of copper. But this ore is ſeldom met with.

Mercury, which is alſo called quickſilver, cannot eaſily be extracted from cinnabar by mere heat; for the mercury and the ſulphur being both volatile, are ſublimed together, without alteration, in cloſe veſſels. An intermediate fixed ſubſtance muſt therefore be uſed, whoſe affinity with the ſulphur is greater than that of the mercury. There are many ſuch, but iron is moſt frequently made uſe of. If iron-filings and pounded cinnabar be mixed,

and

and ſubmitted to diſtillation in a retort, the iron combines with the ſulphur, forming a pyritous compound, and the mercury paſſes over in fumes, which are condenſed by water previouſly put into the receiver for that purpoſe.

This metallic ſubſtance is ſingular in poſſeſſing a very great degree of fuſibility and volatility. Its color is of a ſhining white, and it does not appear to be ſuſceptible of ruſt from expoſure to the air. Gold and platina excepted, it is the heavieſt body known. In our climate it is always melted or fluid; but in December, 1763, the cold in *Siberia* was ſo intenſe, that quickſilver was condenſed into a ſoft ſubſtance like pewter. In this ſtate it was malleable, and its flexibility ſeemed to be intermediate between thoſe of lead and tin. The beginning congelation of mercury is at ſeventy-eight degrees of *Fahrenheit*'s thermometer, below the freezing point of water. But the actual conſolidation of mercury was before aſcertained in December, 1759, by the academicians at Peterſburgh, who availed themſelves, during a very ſevere ſeaſon, of the

extreme cold which is produced by the affuſion of ſtrong ſpirit of nitre upon ſnow. This laſt experiment has been repeated at Hudſon's Bay in 1775 *.

Repeated diſtillations of pure mercury produce no change; but if mercury be expoſed in a large flat-bottomed matraſs, with a long neck, open at top, to the greateſt heat it will bear, without volatilizing, its ſurface gradually, in the courſe of two or three months, becomes covered with a red powder, which floats on the fluid mercury without mixing with it. This powder is called precipitate of mercury without addition. It is ſuppoſed to be a calx of mercury, but may be revived merely by increaſing the heat. It is therefore more probably mercury, combined with air in ſuch a manner as to approach to a ſaline ſtate.

Several chemiſts have taken occaſion to object againſt the doctrine of phlogiſton, from obſerving the revival of metallic calces without addition. It is an indubitable fact, that the calces of metals, whether obtained by fire

* See the Philoſophical Tranſactions for 1769 and 1775.

or

or precipitation, are more heavy abſolutely than the metals from which they were produced; and it is as certain, that they produce or give out air when they are reſtored to their metallic ſtate. Why, then, ſay the objectors, ſhould we not attribute the calcination of metals to the addition of the principle air rather than to the ſubtraction of the principle phlogiſton? — Tho' this objection is ſtrong, yet, for want of experiments, it is not ſufficiently deciſive to induce us to give up the very probable and conſiſtent theory of phlogiſton, which ſeems to be ſupported by many other, and independant proofs.

The nitrous acid readily diſſolves mercury, and forms a cryſtallizable ſalt. If this ſalt be ſubmitted to heat, a great part of the acid may be driven off, and a red matter is left, called red precipitate, which has a conſiderable analogy with the precipitate per ſe, or without addition. In fact, all metallic ſalts may be thus decompounded, and deprived of moſt of their acid by mere heat. Their remaining fixed part ſeems to indicate the nature of metallic calces. Thus, the ruſt of iron, verdigriſe or the ruſt of copper, ceruſe

or the ruſt of lead, and other ſimilar ſubſtances, which are uſually termed calces, approach to the nature of ſalt in proportion as they depart from that of metal. An addition of acid brings them into a ſaline ſtate, and perhaps a ſubtraction of the acid they are known to poſſeſs, might reduce them to the ſtate of metal. If this ſuppoſition were confirmed by experiment, as in ſome inſtances it is, it would eſtabliſh the doctrine of thoſe who deny that the phlogiſton is concerned in the calcination of metals. We ſhould then ſay, that the calcination of metals is produced by expoſing them in a very heated ſtate to air, which, by combining in part with the metal, becomes itſelf diminiſhed, and reduces the metal to a ſemi-ſaline ſubſtance, called a calx. The diminution of the air produces an increaſe of weight in the calx into the combination of which it enters; and the reduction cannot in general be produced by mere heat, but requires the apoſition of another body, which, when heated, can abſorb the air. This property is poſſeſſed in a ſurpriſing degree by charcoal, which, on that account, is very uſeful in reducing calces to a metallic ſtate. The great impor-

tance of theſe conſiderations render them deſerving of the utmoſt attention of the experimental enquirer; and their elucidation would probably remove many difficulties relating to precipitates; as pruſſian blue, and the like.

The vitriolic acid, well concentrated, and hot, diſſolves mercury, and forms a combination called turbith mineral, or yellow precipitate, which is inſoluble in water. The marine acid does not attack mercury in its crude ſtate, but with proper management they may be combined in the form of vapor, which adheres to the ſides of the ſubliming veſſel. This ſalt is called corroſive ſublimate. All the other acids may be combined with mercury, by previouſly diſſolving it in the nitrous acid, and afterwards pouring in the acid in queſtion, which ſeizes the mercury, and falls with it to the bottom, in the form of a ſaline precipitate.

We have ſeen, that mercury may be combined with ſulphur in native cinnabar. If mercury be triturated in a glaſs mortar with ſulphur, it combines with it, forming a black powder, called ethiops mineral. This combination becomes more intimate, by expoſing the

the ethiops to heat in a matraſs, by which it is ſublimed, and converted into cinnabar. Repeated ſublimations, and a ſkilful management of the fire, are neceſſary to produce that beautiful factitious cinnabar, which is known in the ſhops by the name of vermilion.

Mercury unites alſo with oils and mucilages by trituration, and by that means is made to enter into the compoſition of many very uſeful medicines.

All the metals and ſemi-metals may be amalgamatized with mercury. This union is difficultly made with copper, more ſo with regulus of antimony, and moſt difficultly of all with iron; inſomuch, that many philoſophers have concluded this laſt combination to be impoſſible.

CHAP.

CHAP. XI.

Of the Semi-metals. Regulus of Antimony. Biſmuth. Zinc. Regulus of Cobalt. Regulus of Arſenic. Nickel.

SEMI-METALS are ſubſtances which poſſeſs all the metallic properties, except malleability and fixity. They are incapable of any conſiderable extenſion under the hammer, and are ſo volatile, that they may be totally ſublimed by fire. Theſe, as we have already enumerated them, are, regulus of antimony, biſmuth, zinc, regulus of cobalt, regulus of arſenic, and nickel.

Antimony is an ore or mineral, of a brilliant leaden color, compoſed of long brittle needles, or parallel ſtriæ. It is compoſed of nearly equal parts of ſulphur, and the ſemimetal regulus of antimony. If antimony be ſubmitted to calcination, the ſulphur is gradually evaporated, and the regulus, being deprived of part of its phlogiſton, takes the form of a grey calx. A more violent heat

fuſes

fuſes this calx, which, according to the management of the fire, coagulates into an opake brown maſs, called liver of antimony, or elſe into a tranſparent hyacinthine glaſs, called glaſs of antimony. But a more perfect calcination renders the reſidue incapable of either fuſion or vitrification. Theſe calces being treated with phlogiſtic matters in cloſe veſſels, are reduced into the ſemi-metal or regulus.

The regulus of antimony is of a dull white color. It is hard and brittle, and ſeems compoſed of ſhining facets; and its ſpecific gravity, being to that of rain-water as 7500 to 1000, is rather greater than that of tin.

Antimony, being ſuppoſed neceſſary to the great work of tranſmutation of metals, which was attempted by the alchemiſts, and which is ſtill purſued by numbers whoſe knowledge of chemiſtry is too ſuperficial to permit them to ſee the great difficulty of their undertaking, has been ſubmitted to a great variety of chemical trials. In conſequence of this, our knowledge of antimony is very conſiderable; and many valuable medicines are obtained from it: but our purpoſe does not admit of extenſive details.

If

If a mixture of antimony, tartar, and nitre, be thrown by ſpoonsful at a time into a red hot crucible, the nitre detonates with the phlogiſton of the tartar, and the ſulphur, which is a part of the antimony. When the whole is put into the crucible, the fire muſt be raiſed to melt the matter, which, when cool, may be obtained by breaking the veſſel. This matter conſiſts of two diſtinct ſubſtances, which may be eaſily ſeparated. At the bottom is the regulus of antimony; and the upper part is a ſcoria, compoſed of the alkaline parts of the nitre and tartar, combined with a portion of the ſulphur, and the regulus of the antimony. It is conſequently a liver of ſulphur, which holds a part of the regulus in ſolution.

All the imperfect metals have a greater affinity to ſulphur than the regulus of antimony has, and are, for that reaſon, employed to ſeparate it from the ore. Iron is moſt commonly uſed. Crude antimony being melted with bits of iron, by a ſtrong fire ſuddenly applied, the ſulphur unites with the iron, and forms a maſs which ſwims at the top of the veſſel, while the regulus occupies the lower part of the crucible. If the

the iron be greater in quantity than is neceſſary to ſaturate the ſulphur, the ſurplus unites with, and vitiates the regulus; it is therefore requiſite to attend to this circumſtance.

In the calcination of antimony, a part always ſublimes in the form of flowers. The whole of this ore may be ſublimed by heat in half-cloſed veſſels, and is then called flowers of antimony. The regulus is alſo capable of ſublimation into flowers, which are called ſilvery flowers, or ſnow, of regulus of antimony. Theſe laſt are eſteemed to be the calx of the regulus, and are reducible by being treated with phlogiſtic matters. But this calx is ſoluble, though difficultly, in boiling water, and therefore ſeems to confirm, in ſome degree, the conjectures relating to the ſaline nature of metallic calces, which were adverted to in the laſt chapter.

The ſimple acids cannot be made to combine with the regulus of antimony without particular management. For this purpoſe the vitriolic acid muſt be concentrated and hot. The nitrous acid rather corrodes and dephlogiſticates than diſſolves it. And the marine acid exerts no action upon it unleſs both be in

the

the ſtate of vapor. If regulus of antimony and corroſive ſublimate be ſubmitted to heat in a veſſel of a proper form, the marine acid of the corroſive ſublimate quits its mercury, and unites with the regulus to which it has a greater affinity: this laſt combination is ſublimed in the form of a very corroſive ſalt, called butter of antimony. The mercury is left at the bottom of the retort, but may be obtained by increaſing the fire. If, inſtead of the regulus, antimony itſelf had been uſed, the laſt product would have been cinnabar, and not mercury; for the ſulphur of the antimony, combining with the mercury, cauſes it to be ſublimed in this laſt form. Cinnabar obtained by this means is called cinnabar of antimony.

The proper ſolvent of regulus of antimony is aqua regia, but this muſt be aſſiſted by heat. If the aqua regia be evaporated, the regulus is left in the form of a white powder, which, when nitrous acid has been twice poured over it, and evaporated by a heat ſufficient to calcine the reſidue, is called bezoar mineral. But in making bezoar mineral, it is better, and more uſual, to diſſolve butter

of

of antimony in the nitrous acid; in which caſe the regulus, after the commotion of the liquor has ſubſided, is held in ſolution by an aqua regia, compoſed of the nitrous acid and the marine acid of the ſalt. The ſubſequent affuſions of nitrous acid and calcinations are managed as before.

Biſmuth is the heavieſt of all metallic bodies, except the perfect metals and lead. It is alſo called tin-glaſs and marcaſite. It appears to be compoſed of cubes, formed by the application of plates upon each other, and is of nearly the ſame glittering color as regulus of antimony. Biſmuth is generally mineralized by arſenic, and its ore almoſt always contains cobalt; but it is ſometimes found native.

This ſemi-metal reſembles lead in many particulars. It may be vitrified, and converted into a kind of litharge; and is thought to be ſuperior to lead for purifying gold and ſilver by the proceſs of cupellation. Its fuſibility is very great, and it very much increaſes the fuſibility of tin, and other metals. And it is ſo volatile, that it may be ſublimed entire in cloſe veſſels, without altering any of its properties.

It

It is not eaſy to combine biſmuth with either the vitriolic or marine acids, but the nitrous acid diſſolves it very well. From this ſolution, by evaporation and cooling, is procured a ſhining white ſalt. But if, inſtead of evaporating and cooling, water be added to the ſolution, the nitrous acid unites with the water, and quits the biſmuth, which falls to the bottom in the form of a white powder. This powder is called magiſtery of biſmuth, or more commonly ſpaniſh white, and when waſhed and dried is uſed as a coſmetic or paint, in which, however, it is pernicious.

Zinc is a ſemi-metal, of a brilliant white. It is ductile in a ſmall degree, and when broken preſents a ſurface, compoſed of ſhining facets, which are larger when ſlowly than when haſtily cooled. It is brittle when heated, and is ſo inflammable that it burns, when expoſed to a white heat, with a flame too bright to be viewed without pain. During this inflammation it ſublimes in the form of a white ſmoke, which, becoming condenſed, floats in the air like ſpiders webs, and is called philoſophical wool, pompholix, or flowers of zinc. Theſe flowers are very fixed, and of the nature

of calces, notwithſtanding their ſubliming by the violent inflammation.

There are various ores of zinc. Lapis calaminaris, or calamine, is the moſt common. It is a yellowiſh ruſty ſtone, found in Cornwall, and other parts, and is generally uſed for making of braſs.

The ſpecific gravity of this ſemi-metal is to that of rain-water as 7215 to 1000. It poſſeſſes the property of not uniting with ſulphur, and may therefore be purified from the imperfect metals by burning ſulphur on its ſurface when melted, which deſtroys the latter. Braſs, and all the various imitations of gold, called princes-metal, tombac, &c. are allays of copper with zinc.

All the acids are capable of acting upon zinc, and form ſaline compounds. White vitriol is a combination of the vitriolic acid with this ſubſtance.

Cobalt is a term which has been uſed with ſome latitude by mineralogiſts; but is now generally underſtood to imply that mineral which contains a regulus or ſemi-metal, whoſe calx furniſhes a blue glaſs when vitrified. Cobalt is of ſeveral kinds, but moſt commonly

monly of a grey color, with ſome degree of brilliancy, and its ſurface, after expoſure to the air, is generally covered with an efflorescence or powder. This ore contains much arſenic, which ſublimes, and is collected in long crooked chimneys during the torrefaction or roaſting, which is neceſſary for procuring either the calx or regulus. The reſidue or calx is of a grey or reddiſh color, and is called zaffre. If zaffre be fuſed with vitrifiable matters, it affords a beautiful blue enamel, called ſmalt, or azure, which is of conſiderable uſe in the arts. But if, inſtead of vitrifiable matters, the zaffre be fuſed with a proper quantity of black flux, which is a phlogiſtic, or coaly alkaline matter, that remains after the detonation of one part of nitre with two parts of crude tartar, a metallic regulus is obtained at the bottom of the crucible. This regulus on examination is found to conſiſt of two diſtinct ſemi-metals, which may be ſeparated at their common horizontal ſurface by the blow of a hammer. The lower part is the ſemi-metal biſmuth, which is almoſt always contained in cobalt, and the

upper part is the regulus of cobalt, whoſe calx poſſeſſes the diſtinguiſhing property of imparting a blue to glaſs, which is proof againſt the utmoſt violence of heat.

Regulus of cobalt is a hard, brittle, cloſe-grained ſemi-metal, of a ſilvery white, very brilliant when newly produced, but ſubject to tarniſh in the air. It ignites long before it fuſes, and requires for this laſt purpoſe a heat ſufficiently great to melt copper. Its fixity is much greater than that of any other ſemi-metal, but it may be volatilized by an intenſe heat. A leſs degree of heat, with acceſs of air, reduces it to a blackiſh calx, which forms the beautiful blue glaſs before-mentioned, by fuſion with vitrifiable matters.

The regulus of cobalt is not acted upon by either the vitriolic or marine acids, but by means of heat, and a ſkilful management of circumſtances. The nitrous acid attacks it with impetuoſity, and forms olive colored cryſtals of ſalt, by evaporation, which are very deliqueſcent. The properties of this ſemi-metal, are not much known.

Arſenic

Arſenic is a ſubſtance, which, as far as it is yet known, cannot with propriety enter into any claſs of bodies. It conſiſts of the white flowers which are obtained in the torrefaction of ſeveral ores, but particularly that from which cobalt is obtained.

Arſenic appears to be a metalline calx; for if it be combined with phlogiſtic matters, it ſublimes in the form of a ſcaly brilliant ſubſtance, which has the metallic opacity, weight, and luſtre, and is called regulus of arſenic.

Yet the volatility of arſenic conſtitutes an eſſential difference between it and metalline calces: beſides which, it eaſily unites with all metals and ſemi-metals; a property which no other ſubſtance, not actually in a metallic ſtate, poſſeſſes.

But this ſingular body, notwithſtanding the properties we have juſt enumerated, poſſeſſes many of the diſtinguiſhing characters of ſalts. It is ſoluble in water and in acids, and acts even as a ſtrong acid in the perfect neutralization of alkalis.

Sulphur combines with arſenic, and forms compounds of a yellow or red colour, accord-

ing as the proportion of the latter is greater or leſs. The yellow is called orpiment, and the red reagal or riſigal. Theſe combinations, as alſo arſenic, and even its regulus, are ſometimes found native.

The combinations of arſenic with acids have not been enough examined. Its ſolution in water yields by evaporation red and irregular cryſtals. If arſenic be added to nitre, and the mixture ſubmitted to diſtillation, the arſenic acts as an acid, by combining with the alkaline baſe of the nitre, and detaching its acid. The nitrous acid therefore paſſes over into the receiver, together with a ſmall portion of the arſenic, while the bulk of the arſenic remains behind in combination with the alkali, forming a ſalt. This ſalt is termed neutral arſenical ſalt, and, after the uſual purification by ſolution, filtration, and evaporation, may be obtained in beautiful cryſtals.

Arſenic and its combinations are uſed by dyers and other artiſts. It is not applied to any purpoſe in medicine, being a moſt violent and corroſive poiſon. The beſt antidotes againſt its effects, when taken, are diluting

or emollient drinks, as mucilages and oils. Soap might perhaps be a ready and advantageous remedy, as the alkali of this ſubſtance, by combining with the arſenic, might diminiſh its violence by neutralizing it.

The laſt ſemi-metal is nickel. It is of a white colour inclining to red, and its ſpecific gravity is to that of rain-water, as 8500 to 1000. Its fixity is conſiderable, and its calx is green. It is ſoluble in all the acids, though difficultly in the vitriolic; and all theſe ſolutions have a deep green colour. The vitriol formed of it is likewiſe green, and this vitriol, as alſo the precipitates from the ſolution, are green when calcined. But no copper can be obtained by reducing the precipitates. Except ſilver, quickſilver, and zinc, it unites with all metallic ſubſtances. It ſtrongly attracts ſulphur. A ſtrong fire is neceſſary to melt it, which does not follow till ſome time after ignition.

This ſubſtance is obtained from a reddiſh yellow mineral, called kupfer nickel, which contains alſo iron, regulus of cobalt, arſenic, and ſulphur. It has been conjectured that nickel is a kind of regulus of cobalt; but

the preſent ſtate of our knowledge does not enable us to determine on the matter.

CHAP. XII.

Of Saline Subſtances.

HAVING diſpatched the firſt general claſs of compound bodies, namely, the inflammable, or ſuch as contain phlogiſton, we ſhall now proceed to treat of the ſecond claſs, which conſiſts of ſubſtances which are either diveſted of that principle, or elſe combined with it in ſuch a manner and proportion as to be incombuſtible. Theſe are pretty accurately denoted by the general term ſalt.

The general definition of ſalt is, that it is a ſubſtance which is uninflammable, and ſoluble in water.

This definition comprehends thoſe bodies which are called acids and alkalis, as well as more compounded matters. Acids and alkalis were always termed ſalts by the old chemiſts; but many of the moderns have with reaſon confined the word to denote ſubſtances which

which are evidently compounded. Theſe almoſt always conſiſt of an acid combined either with an alkali, a metal, or an earth. The ſubſtance, which, by uniting with an acid, forms a ſalt, is called its baſe.

We have frequently adverted to the great variety which ſubſiſts in nature, and have obſerved the imperfection which muſt conſequently attend all general claſſification. The conditions of any definition are always found to agree more perfectly with one ſpecimen of the claſs than another; which evinces, that we are yet far from the knowledge of the firſt principles of bodies. In the preſent inſtance, ſolubility in water is the criterion by which ſalts are diſtinguiſhed from earths: yet, if we attend to the various degrees of ſolubility, we muſt ſee that the limitations of each claſs approach by a gradation which is imperceptible. Selenites, or the ſalt which is compoſed of the vitriolic acid united with calcareous earth, is ſoluble in very ſmall quantity. Pure calcareous earth is likewiſe ſo. The ſaline combination of an alkali with vitrifiable earth, called liquor of flints, is ſoluble in water: a ſimilar combination in which the proportion

of alkali is leſs, becomes glaſs, and is inſoluble, at leaſt to ſenſe and common experiment. In theſe and many other inſtances, the difference is not in ſpecie, but in degree only; and therefore, it does not appear inaccurate or improper, to denote all uninflammable combinations by the term ſalt.

There are alſo ſalts of conſiderable ſimplicity, which contain phlogiſton, and are inflammable. Such are tartar and the volatile alkali, both which are ſufficiently phlogiſticated to cauſe a detonation with nitre.

Sapidity or taſte is uſually reckoned as one of the properties of ſalts; but this obſervation does not ſeem to render the definition more accurate. Sapidity is a degree of cauſticity, which ariſes from the whole elective attraction of one or more of the principles of a body, not being ſaturated, and which can act upon the tongue. Salts are therefore more or leſs ſapid, accordingly as this ſaturation is leſs or more perfect. Thus ſelenites is inſipid, common ſalt is pungent, but lunar nitre is intolerably cauſtic.

The method of obtaining ſalts in a ſtate of purity is founded chiefly on their property

of

of combining with water. Thus, * vitriol is obtained, by diſſolving the efflorescence of pyrites in water. And as, in general, they are leſs volatile than water, they may be deprived of it by evaporation. The greater number of ſalts are ſoluble only in a certain proportion in water, and form a brine, which, when ſaturated, will act no more upon the ſpecies of ſalt made uſe of: but there are others which combine with water in all proportions, and form a magma. If a ſolution of the former be expoſed to heat, the brine becomes more and more concentrated by the evaporation of the water, and part of the ſalt, being no longer held in ſolution, becomes ſolid in the form of cryſtals, whoſe figure is different, according to the nature of the ſalt. This is called cryſtallization, and the ſalts are called cryſtallizable. But a ſolution of the latter kind of ſalts only becomes more and more thick by evaporating the water, and at length dry. Theſe ſalts in general attract the moiſture of the air, and become again fluid; whence they are termed deli-

queſcent.

queſcent. Several cryſtallizable ſalts will deliqueſce, if expoſed to the moiſture of the atmoſphere; and others, on the contrary, will dry, and fall into a powder or efflor-eſcence. A certain proportion of pure water enters into the compoſition of the cryſtals of ſalts, which is called the water of cryſtalliza-tion. In many ſalts this water may be driven off by heat, and others may be deprived of it by efflorescence, without altering their properties.

Heated water, for the moſt part, will hold a greater quantity of a given ſalt in ſolution, than water which is more cold. This vary-ing ſolubility, which depends upon the tem-perature, is exceedingly different in different ſalts.

In order therefore to procure ſalt in a pure ſtate, the ſubſtance containing the ſalt is mixed with a ſufficient quantity of water, which becomes impregnated with the ſaline matter. The water or brine is then ſeparated from the indiſſoluble impurities by filtration or ſtraining, and the ſalt is obtained either in cryſtals or in a maſs, by boiling and evapo-rating the water.

The

The chief difficulties that attend this proceſs, are, firſt, that ſeveral different kinds of ſalt may be contained in the ſame ſubſtance, which muſt conſequently all be diſſolved together in the water: and ſecondly, that ſeveral ſaponaceous or mucilaginous matters may be diſſolved, which are not only incapable of cryſtallization themſelves, but prevent the cryſtallization of the ſalts. The laſt particular is that which is the moſt embarraſſing; but chemiſtry affords methods to obviate both.

Since no two ſalts agree exactly in ſolubility, they may be ſeparated by means of this difference. Thus, for example; a ſolution of nitre and common ſalt being given, it is required to ſeparate them from each other. This is effected by a ſlow evaporation of the water; for common ſalt being much leſs ſoluble than nitre, begins to cryſtallize much earlier, and may be taken out with ladles; and the nitre, by cooling, at laſt cryſtallizes in a ſtate of conſiderable purity. This operation muſt be repeated three times, by adding freſh water, before the nitre is ſufficiently pure to make gun-powder.

The

The mucilaginous matter which prevents cryſtallization, always accompanies the native or combined ſalts of vegetables. For this reaſon it is, that the decoctions of vegetables, or their expreſſed juices, inſtead of affording the ſalts, are reduced to the ſtate of an extract by boiling. This difficulty may be avoided, either by treating the vegetable with ſpirit of wine, which diſſolves the ſalt without affecting the mucilage, or by adding certain matters, as clays, calcareous earths, or alkalis, to the watery decoction or juice, which forward the cryſtallization, either by combining with the mucilage, or by ſome other action which has not been ſufficiently explained. The firſt of theſe methods is never uſed, on account of the expence; but it is by means of the latter, that tartar is converted into that pure white ſalt, called cream of tartar; and ſugars are refined into ſugar-candy or loaf-ſugar. Vegetable ſalts are all very much compounded, and contain phlogiſton: and it may be expected, that the laudable induſtry of the chemiſts of the preſent age will diſcover ſome method of ſhortening the tedious and difficult proceſſes by which they are now obtained.

TABLES

ACIDS combined with	BASES. Vegetable Alkali.	Marine Alkali.	Volatile Alkali.	Calcareous Earth.	Argillaceous Earth.
VITRIOLIC.	Vitriolated Tartar.	Glauber's Salt.	Vitriolic Ammoniac.	Selenites.	Alum.
NITROUS.	Nitre.	Cubic Nitre.	Nitrous Ammoniac.	Nitrous Selenites.	Little known.
MARINE.	Regenerated Sea Salt.	Sea Salt.	Sal Ammoniac.	Liquid Shell, or Oil of Lime.	Unknown.
ACETOUS.	Regenerated Tartar.	Sal Diureticus.	Spirit of Mindererus.	Little known.	Unknown.

ACIDS combined with	BASES. Silver.	Copper.	Iron.	Lead.	Mercury.
VITRIOLIC.	Lunar Vitriol.	Blue Vitriol.	Green Vitriol.	Unknown.	Turpeth Mineral.
NITROUS.	Lunar Nitre.	Cupreous Nitre.	Martial Nitre.	Nitre of Lead.	Nitre of Mercury.
MARINE.	Luna Cornea.	Little known.	Little known.	Plumbum Corneum.	White Precipitate. Corrosive Sublimate. Sweet Mercury.
ACETOUS.	Unknown.	Crystals of Venus, or Distilled Verdigrise.	Unknown.	Sugar of Lead.	Little known.

The foregoing two tables ſhew the combinations which produce many of the beſt known ſalts. In each line oppoſite the acid, is written the name of the ſalt, which is produced by combining it with the baſe, which is placed at the head of the column. For example, the marine acid combined with the baſe volatile alkali, produces ſal ammoniac; and ſo of others. Brevity has made it neceſſary to omit a conſiderable number of acids, and alſo ſeveral metals, together with all the ſemi-metals; the reſpective combinations of which would have been very intereſting in a more extenſive work. For the ſame reaſon, we cannot enter into a detail of the methods by which the combinations here ſet down are made. It will alſo be obſerved, in looking over the tables, that the account of moſt of the ſalts has been anticipated in the foregoing part of the preſent ſection. We ſhall only therefore deſcribe the methods by which the mineral ſalts that furniſh the three principal acids are procured. Vitriol has already been adverted to: nitre and ſea-ſalt remain to be ſpoken of.

Nitre

Nitre is peculiar in the circumſtance of its never being found ready formed, as is the caſe with vitriol and ſea-ſalt, but is produced, by a concurrence of circumſtances, in bodies which originally do not contain it. Theſe ſubſtances, with reſpect to the nitre, are called nitre beds.

It is ſaid, that ſmall cryſtals of nitre are naturally formed on the ſurface of the ground in Pegu, Bengal, and ſome places on the coaſt of Africa after the rains. Several plants, for example, turnſole, are found to contain nitre ready formed; but as the quantity is very unequal in plants equally vivid and flouriſhing, and ſometimes none at all, it is juſtly thought to be extraneous to them, and dependant on the ſoil. There are fields in Spain which have immemorially furniſhed nitre, without any particular culture for that purpoſe. And univerſally, the earth of ſtables, pigeon-houſes, cellars, barns, mud-walls, and the mortar of all covered damp places, or inhabited buildings, are found, after a certain length of time, to contain nitre.

The reſult of obſervation on this ſubject, is, that nitre is never found but in

earths, which have been acceſſible to vegetable or animal putrefactive matter, and that the putrefaction muſt have been complete. If vegetable matter be united with the earth, proper nitre, with baſis of vegetable alkali is in general produced; but if animal matter, the nitre is in greater quantity, but almoſt always with an earthy baſis. The beſt nitre beds are ſuch as conſiſt chiefly of calcareous earths, which probably ariſes from their poroſity, by which the acceſs of air, which is neceſſary to complete putrefaction, is promoted.

It is therefore undetermined from whence the nitre, or rather the nitrous acid, proceeds: whether the animal and vegetable acids are converted by putrefaction, or whether an acid from the air attaches itſelf to the putrefactive matter. From very late experiments, there is reaſon to believe, that pure air which is the nitrous acid in a peculiar and permanently elaſtic ſtate.

To extract nitre from the earth in which it is contained, the whole maſs is put into a large veſſel, and water poured upon it, which, after ſome hours, is drained away by a perforation at the bottom of the veſſel. This impreg-

impregnated water is then boiled till it becomes much concentrated, after which, it is poured upon wood-aſhes in another veſſel. By this laſt operation, the nitre, with an earthy baſis, is decompounded, and receives a baſis of fixed vegetable alkali from the aſhes. The lixivium being drained off, is again boiled, by which means a great part of the common ſalt uſually found in nitre earths, cryſtallizes and is taken out, and the nitre itſelf cryſtallizes, when the liquor is removed into proper veſſels, and cooled. It is farther purified by ſolution in a freſh quantity of water, as has already been obſerved in the courſe of the preſent chapter.

There is nothing intricate or difficult in this proceſs, for extracting nitre from the earth in which it is generated; and therefore, it is not very ſtrictly followed by the makers. Some mix the aſhes with the rubbiſh or earth, and boil the lixivium but once; and, indeed, this ſeems to produce a ſaving both of labour and fuel. And in India and Spain, it is ſaid, that the nitre is procured without the uſe of wood-aſhes. The fixed alkali is probably furniſhed by the

plants which have putrefied on the ſurface of the earth in thoſe warm countries; but it may be juſtly ſuſpected, that they loſe a conſiderable quantity of nitre, which, having an earthy baſe, might have been converted into true nitre, by the uſe of the vegetable alkali of wood-aſhes.

Nitre may be melted, and even made red hot, for a ſhort time, without any conſiderable diſſipation of its acid, or other change; but if any ſubſtance containing phlogiſton be brought into contact with nitre, either of the two matters being heated to ignition, a very ſingular and remarkable phenomenon, called detonation, takes place. The acid combines with the phlogiſton, and is ſuddenly diſſipated into air with noiſe and flame, and the alkali is left in a ſtate of conſiderable purity, but combined with fixed air. Detonation is peculiar to thoſe ſaline matters, into the compoſition of which the nitrous acid enters; and in general, thoſe ſalts whoſe baſes attract the acid moſt ſtrongly, poſſeſs this property in the greateſt degree.

Nitrous ammoniac, and ſeveral metallic nitres will detonate to a certain degree by heat

heat alone, without the addition of any other body. This property muſt be attributed to the phlogiſton contained in their baſes.

The detonation of nitre is not well underſtood, but it ſeems to be analogous to the inflammation of oils by the nitrous acid, and probably depends on the ſtrong affinity between that acid and phlogiſton. *If* a piece of red hot charcoal be plunged in the nitrous acid, it is quenched with ſcarce any detonation, the acid not being ſufficiently concentrated in its fluid ſtate to produce the effect. But in nitre, the acid is in a very high ſtate of dephlegmation; being combined with the alkali, which may anſwer much the ſame purpoſe as the admixture of vitriolic acid in the inflammation of oils. And if this be true, the degree of concentration may be greateſt in ſuch nitrous ſalts, as poſſeſs the moſt attractive baſes with reſpect to the acid; and conſequently in theſe, the detonation muſt be the moſt violent.

The great quantity of permanently elaſtic vapour, which is produced by the detonation of nitre, renders it neceſſary for chemical operators to be very cautious in the manage-

ment of their proceſſes with this ſalt: for if the production be very quick, the veſſels will burſt with a great and dangerous exploſion. The detonation depends on the contact between the nitre and the phlogiſtic ſubſtance. If the ſurface of contact be extenſive, the decompoſition muſt be more rapid and ſudden; and contrariwiſe, if the ſurface be leſs, the detonation will laſt longer, and be leſs violent. Thus, if a lump of charcoal be thrown into a ſmall crucible, containing ignited nitre, a vivid and fierce flame will ſurround the charcoal, and the decompoſition will proceed gradually; but if, by pulverizing, the ſame piece of charcoal be made to preſent a much larger ſurface, and it be then added to the heated nitre, the effects will all be much more ſtrong and ſudden. The danger of exploſion is therefore in ſome reſpect diminiſhed, by avoiding a too intimate mixture of the nitre with thoſe ſubſtances which might afford phlogiſton.

But in the making of gunpowder every circumſtance that can promote the ſudden detonation is carefully attended to. Gunpowder is a compoſition of nitre, charcoal and

and ſulphur. The firſt of theſe is that on which its efficacy depends; the charcoal affords phlogiſton, and the ſulphur renders the maſs inflammable at the ſlighteſt touch of an ignited body. In the manufacturing, it is of much more conſequence that the ingredients be intimately mixed, than that the proportions be ſtrictly accurate. One hundred pounds of Engliſh gunpowder is ſaid to contain 75 lb. of nitre, 15 lb. of ſulphur, and 10 lb. of charcoal. Theſe are mixed by continual kneading with water in wooden mortars, with wooden peſtles, whoſe motion is produced by a mill. After the mixture is made, this paſte is rubbed through the holes of a wire-ſieve, by which it is cut into ſmall maſſes or grains, which, for muſquetry, are afterwards ſmoothed, or, as it is termed, glazed, by their mutual friction againſt each other in a barrel, mounted on an axis for that purpoſe. Laſtly, the powder is rendered as dry as poſſible, by means of heated ſtoves, ſo contrived, as to avoid the danger of exploſion. The effects of gunpowder are very much augmented by its granulation; for if a gun be charged with ungrained powder, the fire will be ſucceſſively

communicated; that is to ſay, thoſe parts which are far from the touch-hole will not be inflamed till the parts ſituated nearer are firſt burnt, and exploded: by which means a great quantity of the powder muſt be blown out of the piece without exerting its force. But when the powder is granulated, the exploſion of the firſt ſmall quantity communicates its flame through the empty ſpaces between the grains, and fires the whole almoſt at the ſame inſtant. No wonder then that the effect in this latter caſe ſhould be prodigiouſly greater.

Common ſalt is extracted from mines in the earth, and is then called ſal gemmæ, or rock-ſalt. There are alſo many ſprings which furniſh this ſalt, probably from their paſſing through mines in which it is contained. And the ocean is every where impregnated with about one-thirtieth of its weight of ſalt. From theſe ſeveral ſources it is obtained for culinary, and other purpoſes. In Italy, Spain, and the ſouth of France, a ſtrong, though impure, ſalt is obtained from ſea-water, by receiving it into large ſluices or reſervoirs, and ſuffering it to evaporate by the heat of the Sun,

Sun, till cryſtals are produced. This is called bay-ſalt. In England ſalt is procured moſtly by boiling either the ſalt-water of the ſea, or brine-ſprings, in both which they uſually diſſolve rock-ſalt. The uſe of crude rock-ſalt is prohibited in England; and therefore it is always purified for home conſumption by ſolution and cryſtallization. A part of the acid of ſea-ſalt is driven off by heat, from which circumſtance it happens, that purified ſalt is always ſtronger and more pungent the leſs heat is employed to evaporate the water.

The following table of affinities needs no other explanation than obſerving, that the affinity of any ſubſtance to that which ſtands at the head of the column is greater than that of any other which ſtands beneath it. Thus, the affinity of phlogiſton to vitriolic acid is greater than that of fixed alkali; and the reſpective affinities of the other bodies to the ſame acid, proceeding down the column, are leſs and leſs.

TABLE

VITRIOLIC ACID.	NITROUS ACID.	MARINE ACID.	ACETOUS ACID.	FIXED ALKALI.	VOLATILE ALKALI.	AQUA REGIA.	SULPHUR	LIVER of SULPHUR	VITRIF. EARTH.	CALCAR. EARTH.	MERCURY.
Phlogiſton.	Phlogiſton.	Phlogiſton	Phlogiſton.	Phlogiſton.	Phlogiſton.	Phlogiſton.	F. Alkali.	Gold.	L. of Sulph.	V. Acid.	Gold.
F. Alkali.	Zinc.	Zinc.	Zinc.	V. Acid.	V. Acid.	Zinc.	Iron.	Silver.	F. Alkali.	N. Acid.	Silver.
V. Alkali.	Iron.	Iron.	Iron.	N. Acid.	N. Acid.	Iron.	Copper.	Iron.	Borax.	M. Acid.	Biſmuth.
Abſ. Earths.	Cobalt.	Copper.	Copper.	M. Acid.	M. Acid.	Cobalt.	Tin.	Copper.	Calx of lead.	A. Acid.	Zinc.
Zinc.	Copper.	Tin.	Lead.	A. Acid.	A. Acid.	Copper.	Lead.	Lead.	Calx Antim.	L. Sulphur.	Tin.
Iron.	Biſmuth.	Lead.	Biſmuth.	Zinc.	Zinc.	Tin.	Silver.	Tin.		F. Alkali.	Lead.
Copper.	Lead.	Biſmuth.		Iron.	Iron.	Arſenic.	Biſmuth.	R. Antim.		Borax.	Copper.
Silver.	Mercury.	R. Antim.		Copper.	Copper.	Biſmuth.	R. Antim.	Biſmuth.		C. of Lead.	R. Antim.
Tin.	R. Antim.	Mercury.		Lead.	Biſmuth.	Mercury.	Mercury.	Zinc.		C. of Antim.	
Lead.	Silver.	Arſenic.		Tin.	Mercury.	Lead.	Arſenic.	Cobalt.			
Mercury.	Arſenic.			R. Antim.	Silver.	R. Antim.	Cobalt.				
Biſmuth.	Tin.			Cobalt.	Gold.	Gold.					
R. Antim.				Arſenic.							
Arſenic.				Biſmuth.							

CHAP. XIII.

Of Magnetiſm.

THAT remarkable property which iron poſſeſſes, of becoming magnetical, ſeems to ſtand alone among natural phenomena. It is the only inſtance of permanent attraction which is ſufficiently ſtrong to become the object of vulgar attention; and philoſophers obſerve its effects with ſurprize and admiration, while the moſt cautious and rational are obliged to confeſs that the cauſe is entirely unknown.

A ſtrait bar of iron, which in theſe parts of the world has ſtood a long time in a vertical poſition, is found to have acquired the property of attracting other iron at its extremities; and, if ſupported in a ſmall veſſel, ſo as to float at liberty upon water, conforms itſelf to a direction nearly in the plane of the meridian; the end, which during its perpendicular ſituation was downwards, always pointing towards the North. This bar is ſaid to be

magnetical; and the unknown cauſe of this and other concomitant effects is called magnetiſm.

Magnetiſm may be given to iron, or rather ſteel, by many methods, ſome of which we are about to mention. The diſpoſition to conform to the plane of the meridian is called polarity, and is of ſuch importance in its application, that the modern art of navigation could not exiſt without it. The mariner's compaſs is thus conſtructed. A flat thin bar of ſteel, rendered magnetical, is faſtened underneath a circular card, (fig. 117.) ſo that the direction of its length may correſpond with the line NS. This bar is perforated in the middle; and in the perforation is fixed a braſs cap, hollowed out conically, which conſequently is in the center of the card. The card thus provided with a magnetical bar, is then ſupported horizontally, by placing the cavity of the cap on an upright metallic point, and is therefore at liberty to revolve into any horizontal poſition. But the bar, which is uſually termed the needle, conforming itſelf to the meridian, cauſes the fleur de lis of the card to point to the North; conſequently,

ſequently, the other diviſions muſt denote the reſpective bearings of the points of the compaſs. This card being thus ſuſpended in a hollow box, and defended from the wind by a pane of glaſs, with the addition of a contrivance to prevent the effects of the agitation of the ſhip, is the mariner's compaſs; by the help of which veſſels are enabled to ſteer their courſe with ſafety in the darkeſt night, and at any diſtance from ſhore.

A light magnetical bar ſuſpended in this manner is very ſerviceable for indicating the magnetiſm of other pieces of iron. For a bar of this nature will be ſenſibly moved by the action of another magnetical bar, whoſe power is too weak to be rendered perceptible any other way.

The ends of a ſimple magnetical bar are called its poles; and that pole, which, when at liberty, would point to the North, is called the North pole, and the other is called the South pole.

Univerſally, in two magnetical bodies or magnets, a ſtrong attractive force obtains between the North pole of one, and the South pole of the other, and a repulſive force obtains

tains between poles of the ſame name. But the repulſive force which exiſts between poles of like names, is moſt commonly, and perhaps univerſally, changed into attraction, when the diſtance is ſufficiently ſmall. From theſe criterions it is eaſy to determine the names of the poles of a magnetical bar, by applying it near the ſuſpended magnet, whoſe poles are known.

If a bar of iron, which is not magnetical, be held in a vertical poſition, its lower point becomes a North, and its upper a South pole; and theſe poles may be reverſed inſtantly, and as often as required, by reverſing the poſition of the ends; for the lower will always be North, and the upper South. But a few ſmart ſtrokes with a hammer at the upper end will fix the poles in their laſt poſition, ſo that after the reverſing it the hammered end will ſtill continue to be ſouth, though loweſt. Yet, the magnetical power is much the greateſt when the hammered end is uppermoſt, and the effect of the hammering diſappears in a few hours.

A bar of iron being ſuſpended on an axis, in a very nice equilibrium, the North end preponderates

ponderates when the bar is rendered magnetical, ſo that it becomes inclined to the horizon in an angle of about ſeventy degrees in theſe latitudes. This is called the dip, and decreaſes in places more to the ſouthward, and even becomes inverted in places ſituated conſiderably on the other ſide of the equator. The bar thus ſuſpended is termed the dipping-needle.

Magnetiſm may be given to a bar of iron, by placing it firm in the poſition of the dipping-needle, and rubbing it hard all one way with a poliſhed ſteel-inſtrument. Iron alſo becomes magnetical by ignition, and quenching it in water in the poſition of the dipping-needle.

The touch of a magnet communicates the like virtue to other iron, but the quantity or degree which the ſame magnet can communicate, depends greatly upon the manner in which the touch is performed. If two equal, ſtrait and uniform magnetical bars, with flat ends, be placed together endwiſe, the contrary poles touching each other, they will form one ſingle magnet, and will communicate a ſtrong degree of magnetiſm to another bar by the

the following proceſs: let the laſt mentioned bar be laid in the direction of the magnetical meridian, and let the others, each of which ought to be at leaſt as long as the bar to be impregnated, be laid upon it in their conjoined ſtate, ſo that the place of junction may be over the middle of its length, and their poles in the proper direction. Then ſeparate the two magnets, by drawing them aſunder along the ſurface of the bar, and continue to ſeparate them till their ends are at a conſiderable diſtance from its ends. Join them again without altering the ſituation of their poles, by a circular motion of the hand, ſo that they may meet at ſome diſtance above the center of the bar, and lay them again upon it as before. Repeat this operation on both ſides of the bar till it has acquired a ſufficient degree of magnetiſm. The maximum is generally obtained after twelve or fourteen ſtrokes.

A bar of iron receives the touch more ſtrongly when it is ſupported by, or in contact with, another much larger; and a combination of magnetical bars will produce a much greater effect than a ſingle one. Soft

ſteel acquires the magnetical power more readily, but does not preſerve it ſo long as hard ſteel. On theſe, and other conſiderations, experiments have been multiplied, and various methods invented of giving to ſteel the utmoſt degree of magnetiſm it is capable of receiving. For example, ſix bars of ſteel may be rendered ſlightly magnetical, by affixing each ſucceſſively to a poker, and ſtroking it ſeveral times from bottom to top with the lower end of a pair of tongs; care being taken to keep both the poker and tongs in a vertical poſition. For, theſe utenſils, by long ſtanding in a vertical poſition, are almoſt always poſſeſſed of a fixed magnetiſm; the lower ends being North poles. Now, if four of the ſix bars be united into a thick compound bar, the magnetiſm of the remaining two may be greatly increaſed by touching with it. Theſe two bars may then be ſubſtituted in the room of the two outermoſt in the compound bar, which will become more powerful by the exchange, and the two which were taken from the compound bar may be touched in their turn. Thus, by reiterated changes, and touching, the bars will at length acquire as

much magnetiſm as they are ſuſceptible of receiving.

The force of magnetiſm is exerted through all ſubſtances, iron excepted, and it has not been obſerved, that it ſuffers the leaſt diminution by the interpoſition of any foreign matter. Magnetiſm is deſtroyed by ignition; and a heated bar of iron is not attracted by the magnet till it is juſt upon the point of loſing its redneſs.

The loadſtone is a ponderous ore of iron, uſually of a dirty black color, and hard enough to emit ſparks with ſteel. It is found in moſt parts of the world, and poſſeſſes a natural magnetiſm, acquired moſt probably from its ſituation or poſition with reſpect to the earth. This magnetiſm may be, as it were, concentrated, and made to act much more ſtrongly by covering its polar extremities with ſteel. The ſteel thus applied is termed the armour of the loadſtone, and requires ſome management, as to figure and thickneſs, to produce the greateſt poſſible effect. Formerly all magnetiſm was originally obtained by communication from the loadſtone, but at preſent the power of ſteel-bars, impregnated by arti-

ficial means, ſo much exceeds that of the natural ſtone, that this latter is little eſteemed, except as a matter of curioſity. The magnetiſm of the loadſtone is in all reſpects ſimilar to that of a bar of iron or ſteel.

The attraction or repulſion of two magnets decreaſes as the diſtance increaſes, but not according to any ratio of the diſtance. On this account a magnetical bar, which is at liberty to aſſume any horizontal poſition, as, for example, a needle floated on water by means of cork, or the needle of a mariner's compaſs, being brought into the vicinity of another magnet, will aſſume ſuch a ſituation as ſhall reſpectively ſatisfy the attractive and repulſive powers as much as poſſible. Thus, if a ſuſpended magnetical needle be brought near another magnet, it will place itſelf in a poſition parallel to the axis of the magnet, if the poles of contrary names in each be mutually equidiſtant; but if the North pole of the ſuſpended needle be nearer the South pole of the magnet than the two other poles are to each other, its North end will be moſt attracted, and conſequently muſt incline, ſo that the axes of the two magnets will form an angle greater

or leſs according to circumſtances. Suppoſe now a ſmall magnetical bar, ſuſpended ſo as to be capable of aſſuming any poſition whatſoever, be placed upon, or near the ſurface of a very large globular magnet. It is evident, in this caſe, that the two ends of the ſmall bar, being reſpectively attracted by the contrary poles of the globe, will always be found in the plane of a flat ſurface paſſing through thoſe poles: or, in other words, if circles or meridians be ſuppoſed to be deſcribed on the globe, interſecting each other in thoſe poles, the magnetical bar muſt always be in the plane of one of them. But its ſituation with regard to the ſpherical ſurface will be governed by the exceſs of attraction in the neareſt pole. If the bar be ſuſpended immediately over the North pole of the magnet, it muſt ſtand perpendicularly, with its South end downwards; but if it be gradually removed along the ſurface, towards the South pole, the increaſing action of this laſt pole will cauſe it gradually to incline that way. At the equator it will reſt parallel to the ſurface; and in approaching ſtill nearer, its North end will incline towards the ſurface till at length it

will

will ſtand perpendicularly over the South pole of the great magnet, with its North end downwards. For the ſake of conciſeneſs, the poles of the great magnet are ſuppoſed to be equally ſtrong; which, however, is ſeldom the caſe in reality.

This reaſoning may be exemplified by placing a ſmall piece of ſewing-needle on the ſurface of a ſpherical magnet or loadſtone. Its poſition is found to vary according to its ſituation with reſpect to the poles. For the ſame reaſons, ſteel-filings gently duſted through a rag upon a magnet adhere to it in a very curious and amuſing manner. The filings, acquiring magnetiſm by the contact, adhere together, and form a number of ſmall magnets, which arrange themſelves in conformity to the attractions of the poles of the original magnet.

From obſervations of this nature, it was very early ſuppoſed, that the globe of the Earth acts as a large magnet upon all other magnets: whence they naturally tend to conform to the meridian or line which joins the poles of the Earth. And the dipping of the needle is readily explained to ariſe from the

vicinity and conſequent ſtronger attraction of the pole towards which the inclination is made. The needle of the mariner's compaſs varies from the true direction of North and South. The angle formed between the magnetical axis of the needle and the meridian of a given place is called the variation of the compaſs, and differs in different places both in quantity and direction of the needle. From the phenomena of the variation it is proved, that the magnetic poles of the Earth muſt be more in number than two, and that they do not coincide with the poles about which the diurnal rotation is performed.

The variation of the compaſs does not continue fixed and unalterable at a given place, Thus, at the Cape of Good Hope in Africa, near which, at its firſt diſcovery by the Portugueſe, there was no variation; the North point of the compaſs in 1622 varied about 2°. to the weſtward; in 1675 it varied 8°. W. in 1700 about 11°. W. in 1756 about 18°. W. and in 1774 about 21½.° W. Regular, though very different mutations have been obſerved in almoſt every other place on the globe. The needle of the compaſs is likewiſe ſubject to a

ſmall

small diurnal change of position, and is sometimes considerably agitated during the appearance of the *aurora borealis*.

The observations which relate to the magnetism of the Earth have not been continued long enough to afford a foundation for a good theory. Dr. Halley's hypothesis, though formed near a century ago, still remains the only one which seems at all adapted to the phenomena. He supposes the Earth to consist of two distinct parts, an external shell, or hollow sphere, and an internal nucleus or globe, loose and detached in the cavity, having the same center of gravity with the external part. Each of these parts he regards as a separate magnet, endued with two poles, their magnetical axes not being coincident. A compass-needle on the external surface must therefore be acted upon, as if by a magnet with four poles. From the phenomena he determines the situation of the several poles; and thus explains the variation. But as the variation changes in process of time at any given place, it follows, that these poles do not keep the same position with respect to the surface of the Earth, and to each other. This movement

he accounts for, by ſuppoſing that the diurnal motion of the Earth was impreſſed from without, and that the velocity of the internal part, or nucleus, is ſomewhat leſs than that of the external part, or ſhell. Conſequently the nucleus muſt ſeem to revolve ſlowly to the weſtward, and its poles muſt deſcribe leſſer circles about the poles of the Earth. And as the relative poſition of the four magnetical poles to each other, and to the poles of the Earth, is changed, ſo muſt likewiſe the direction of the needle, or the angle it makes with the meridian, be altered.

Thus, a kind of regularity prevails in the increaſe and decreaſe of the variation, and alſo the direction of the variation which ſhips obſerve as they ſail to various parts of the ocean. In the Atlantic ocean to the North, and eaſtward, and all over the Indian ocean, except in the bay of Bengal, a weſterly variation obtains; but to the weſtward of a certain line, at which there is no variation, all along the coaſt of South America, and in the Pacific ocean, as far as the 140th degree of weſt longitude, an eaſterly variation is obſerved; and in the whole Pacific ocean beſides, the

variation is probably to the weſt, unleſs we may conjecture that an eaſterly variation may be found in the regions to the northward.

When the variation changes quickly in running upon a parallel, as is the caſe in the ſouthern Atlantic, and great part of the Indian ocean, the longitude may be determined with a conſiderable degree of correctneſs at ſea. The author of this treatiſe knows from experience, that the magnetic azimuth of the Sun may be eaſily obſerved in moderate weather to the certainty of a leſs error than ten minutes of a degree: and the true azimuth is obtained from the Sun's altitude, taken at the ſame time by an aſſiſtant. Their difference is the variation. Now, on the parallel of 36°. South, for example, the variation changes 30′. for every degree of longitude: the obſerver, therefore, who knows the quantity of the variation within one-third of that quantity, can, by means of a chart of the variations, diſcover his longitude to leſs than one-third of a degree; which, upon that parallel, is equal to no more than the inconſiderable error of five leagues. But the great impediment to this method is the want of a chart; for the

the continual change of the variation makes it neceſſary that it ſhould be renewed at the end of every three or four years. This ſhort time of ſale cannot poſſibly repay the charges of the compiler. Individuals are therefore deterred from engaging in a labor, which, though beneficial to ſociety, cannot fail of being attended with loſs to themſelves.

to face p.331.Vol.III.

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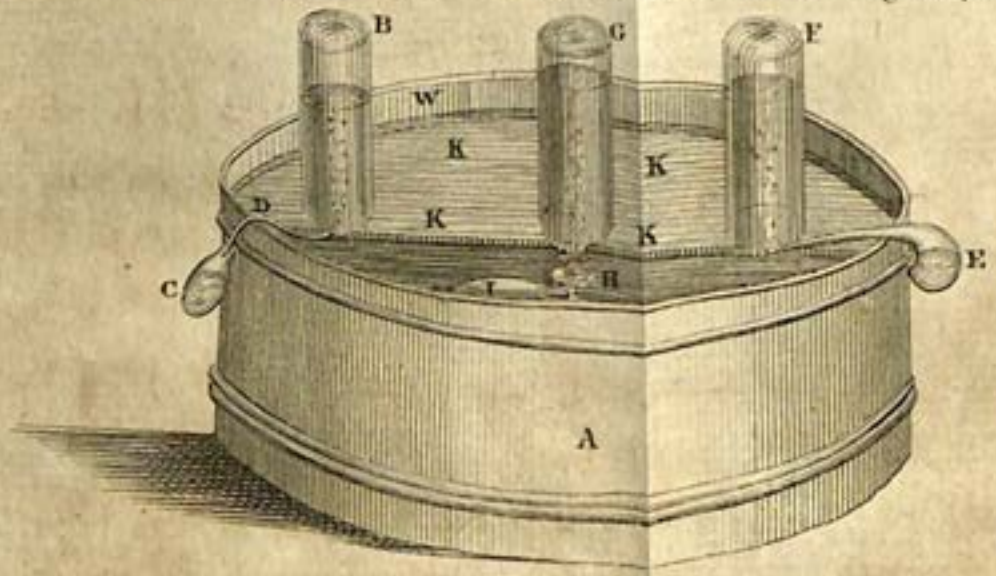
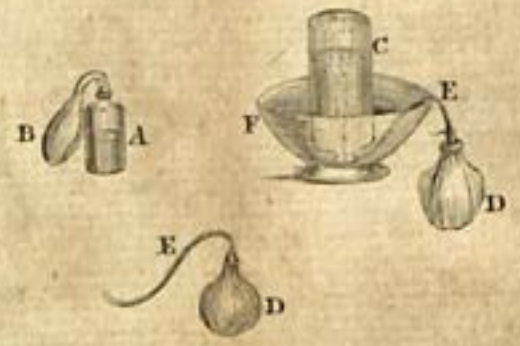
Apparatus for making Experiments on Air Fig.134.p.332.



Impregnation of water with fixed Air. Fig.135.p.347.



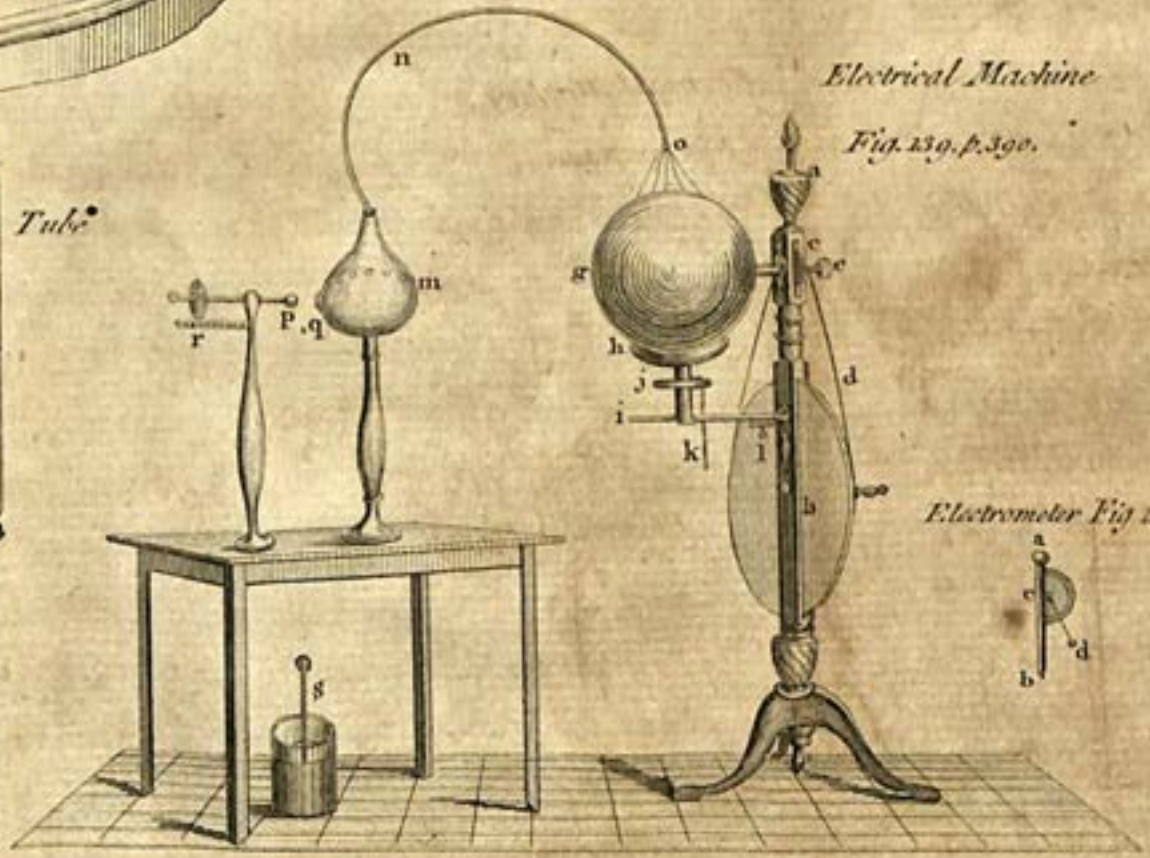
Impregnation of water with fixed Air.

Fig.136.p.349.

Eudiometer Tube Fig.138.p.357.

Fig.137.p.349.

Electrical Machine Fig.139.p.390.



Electrometer Fig.140

BOOK III.

SECT. II.

Of Air.

TILL very lately air has always been conſidered as an elementary and ſimple ſubſtance, and no one attempted to analyſe it: and in chemical reſearches that elaſtic and inviſible fluid which eſcapes during fermentation and ſolution, and which in diſtillation renders it neceſſary to perforate the receiver, in order to prevent the exploſion of the veſſels, has been ſcarcely, if at all, examined into. But at preſent every elaſtic fluid or vapor, which can be obtained in ſuch a ſituation as to preſerve its elaſticity without any conſiderable diminution by cold, is called air. Vapor, therefore, is an elaſtic fluid, which may be condenſed into a palpable ſubſtance by cold, but air cannot be deprived of its elaſticity but by combination.

CHAP.

CHAP. I.

Of the Method of making Experiments; and of reſpirable Air.

THE moſt convenient method of preſerving the various kinds of air from communicating with the external air is, to make uſe of glaſs-veſſels, whoſe mouths are immerſed in water, or ſome other fluid. Let A (fig. 134.) repreſent a tub; KKKK is a ſhelf fixed within, for the purpoſe of ſupporting the inverted glaſs-veſſels. Water is poured in the tub to the height W. When it is required to fill a jar either wholly or in part with air, the veſſel is filled with water by plunging it in the tub, and then carefully placed on the ſhelf with its mouth downwards, ſo that one of its edges may a little overhang the edge of the ſhelf. By the preſſure of the atmoſphere the jar continues full of water; but if another veſſel, containing air, be brought underneath, and the mouth of this laſt veſſel turned up, the air will ruſh out,

out, and riſe to the upper part of the jar, expelling an equal bulk of water. Thus, the veſſel G being previouſly filled with water, and inverted, receives the air which is poured out of the bottle I through the funnel H. C is a ſmall cryſtal-glaſs bottle, or retort, into the neck of which the bent tube D is fitted by grinding. It contains ſubſtances, which, by efferveſcence or otherwiſe, produce air. The other end of the tube is inſerted under the jar B, into which the factitious air riſes, and is preſerved for examination. E is a ſmall retort, which is applied to the ſame purpoſe as the bottle D. Being formed of green glaſs, and all in one piece, it is much cheaper, and will bear the application of a greater degree of heat when required. When heat is neceſſary, a large candle or chafing-diſh of coals may be placed underneath the veſſel C or D; but if a ſtill greater degree be required than glaſs can ſuſtain, an iron retort or gun-barrel may be uſed.

It is proper to obſerve, that all glaſs-veſſels, which are deſigned to ſuſtain the ſudden application of heat without breaking, ought to be made very thin. It will likewiſe be uſeful

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to the operator to be reminded, that glaſs-veſſels may be readily cleanſed from the ruſt of iron, and other metallic impurities, by previouſly rinſing them with a ſmall quantity of the marine acid.

If the air, which it is propoſed to examine, be of ſuch a nature as to combine readily with water, a ſmaller apparatus may be made uſe of, in which quickſilver is ſubſtituted. There are alſo ſeveral other contrivances, of which the experimenter may avail himſelf, by conſulting the writings of Dr. Prieſtley: and there are many particulars which his own obſervation cannot fail to ſuggeſt.

It has long been obſerved, that the common air of the atmoſphere is capable of combining with many ſubſtances. From this cauſe water is held in ſolution by the air; and rain, ſnow, or hail, appear to be precipitations which may, perhaps, be cauſed by the matter of electricity combining with the water, and detaching it from the air, in the ſame manner as the marine acid precipitates metallic ſubſtances from the acid of nitre. As water may be combined with and diſſolved in air, ſo likewiſe air may be diſſolved in water. The affinities of the different

different kinds of air to other bodies are various, and they are conſequently met with in combination, and may, by proper management, be obtained in a detached ſtate.

Common air is diminiſhed in bulk by every proceſs in which phlogiſton is ſaid to eſcape from bodies. Combuſtion, the calcination of metals, the exhalations of liver of ſulphur, white paint, vegetable flowers, and various inflammable matters, putrefaction, reſpiration of animals, and the electric ſpark, phlogiſticate the atmoſpheric air. The greateſt diminution of air by phlogiſtication is about one-fourth of the firſt quantity; and air which is diminiſhed to its utmoſt by any one proceſs cannot be farther affected by any other. Combuſtion, the calcination of metals, and the reſpiration of animals, cannot be performed in phlogiſticated air; they therefore ceaſe at a certain period of the proceſs when incloſed in a given quantity of air: if the quantity be greater, the combuſtion continues longer, a greater quantity of metal may be reduced to a calx, or the death of the incloſed animal is retarded. With regard to the effect of phlogiſticated air on animal life, there ſeems to be

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ſome poſitive action, beſides the mere privation of reſpirable air; for an animal plunged in a veſſel of noxious air dies much more ſuddenly and irrecoverably than in the vacuum of an air-pump.

The combination of phlogiſton with reſpirable air, and its conſequent diminution in bulk, might naturally be expected to produce an increaſe of denſity. But the contrary appears rather to be the caſe. This circumſtance ſeems to depend upon a precipitation which takes place of one of the principles of the air. For, if the operation be carried on in lime-water, inſtead of common water, the lime is precipitated, and upon examination is found to be no longer cauſtic. The cauſticity of the lime may be reſtored by heat, which at the ſame time expels a conſiderable quantity of a denſe air, which we are to deſcribe under the name of fixed air. It therefore follows, that, during the phlogiſtication of common air, fixed air is precipitated; and conſequently that the reſidue may be either denſer or rarer accordingly as the denſity and other properties of the phlogiſton may prevail: but of theſe properties we know very little. Neither has

it

it been determined whether fixed air exiſts in the atmoſphere ready formed, or is produced by a combination which may take place between phlogiſton and one of the principles of the atmoſphere.

Air diminiſhed by calcination does not precipitate the lime from water. This is pretty well accounted for, by ſuppoſing the affinity between fixed air and metallic calces to be greater than between the former and lime or water; the precipitated fixed air therefore muſt combine with the calx inſtead of the lime. The increaſed weight of metallic calces, and the air they are found to contain, afford an additional confirmation of this.

Every ſpecies of air may be totally, and almoſt inſtantaneouſly, abſorbed by charcoal heated red hot, or, which has been heated red hot, and extinguiſhed, by plunging it in quickſilver, without afterwards expoſing it to air. The quantity of air which may be thus abſorbed is many times the bulk of the charcoal employed. In order to repeat this experiment, let a jar, partly filled with quickſilver, and partly with any ſpecies of air, be inverted into a baſon of quickſilver; and let

pieces of charcoal, which have been previouſly ignited, and extinguiſhed in the quickſilver, without having been afterwards expoſed to air, be ſlipped under the jar. They will immediately riſe to the ſurface, and come into contact with the included air; part or all of which air, according to its quantity, relatively to the quantity of charcoal, will almoſt inſtantaneouſly diſappear.

The noxious quality of air, which has been phlogiſticated by reſpiration, has been ingeniouſly applied to explain the facts related by travellers, that animals are killed by the breath of whales, and particularly by the breath of an immenſe ſerpent that inhabits the banks of the river Amazon. For the air reſpired by thoſe very large creatures may be ſufficient totally to envelope ſmaller animals, and to exclude the air during a ſmall portion of time, which, however, may be ſufficient for this noxious air to produce its fatal effect.

The denſity or rarity of atmoſpherical air within certain limits, is not of ſo much conſequence to reſpiration as might be imagined. For the air at the ſummits of mountains is frequently not more than half the mean denſity

ſity of the air at the level of the ſea, but is nevertheleſs breathed without inconvenience. And Dr. Halley remained an hour and an half at the bottom of the ſea in the diving-bell, without any ill conſequence, at the depth of ten fathom, care being taken to renew the air. Now, the preſſure of ten fathom of ſea-water is almoſt equal to that of two atmoſpheres, and conſequently the air in that ſituation muſt have been compreſſed into one third of its original ſpace.

The long expoſure of air to the phlogiſtic emanations in coal mines, and other ſubterraneous places, and the actual production of noxious air, which is occaſioned by the ſpontaneous proceſſes which are carried on in the bowels of the earth, gives birth to the damps which are ſo fatal to miners. And ſince, upon the whole, the daily combuſtion of fuel, the reſpiration of animals, and the putrefaction of animal and vegetable ſubſtances, muſt continually vitiate a great quantity of air, it is of conſequence to enquire what proviſions there are in nature to counteract a depravity, which would otherwiſe put an end to the life of every creature on the ſurface of the earth.

Noxious air is meliorated by agitation in water. It is therefore probable, that the continual circulation of water, by evaporation, which falls again in ſhowers, may contribute much to preſerve the purity of the atmoſphere. But vegetation is more particularly effectual in this reſpect. If the freſh leaves of any plant be put into an inverted jar, containing water, and expoſed to the direct light of the Sun, they emit a conſiderable quantity of air, which poſſeſſes all the properties of the pureſt atmoſpherical air, but in a much higher degree; as is proved from its greater aptitude to promote combuſtion, and the difficulty of rendering it noxious by any of the proceſſes which injure common air. This is termed dephlogiſticated air, and obſervation evinces, that it is not really produced from the plant, but conſiſts of air which is imbibed in its phlogiſtic ſtate, and again emitted in a ſtate of purity.

Dephlogiſticated air is obtained by expoſing either red lead, or the precipitate per ſe of mercury, to heat; or, by heating any dephlogiſticated earth or alkali, which has been previouſly moiſtened with the nitrous acid. In the

the firſt inſtances, it is probable that the calces of lead and mercury only gave out that pure air which had before combined with them during their calcination; but the latter ſeems to point out the conſtitution of dephlogiſticated air. For the ſame earth will, by repeated moiſtening with the nitrous acid, be rendered capable of producing freſh quantities of pure air, till the earth be intirely conſumed. It is therefore probable that dephlogiſticated air conſiſts of the ſimpleſt or elementary earth, combined with an acid in a ſtate of permanently elaſtic vapor.

Dephlogiſticated air may be expelled by heat from almoſt all the ſaline combinations of the vitriolic acid. The acid of this air, if the expreſſion may be uſed, conſiſts then of ſomething which is common both to the nitrous and vitriolic acids, and the earth conſiſts of ſomething which is common to the metalline, calcareous, argillaceous, and alkaline earths. A decompoſition of pure air muſt therefore be an exceedingly intereſting phenomenon, ſince we might thence obtain an acid, or an earth vaſtly more ſimple than any ſubſtance

to which chemiſts have given the name of element.

Dr. Prieſtley, whoſe induſtry in this department of natural philoſophy has been crowned with peculiar ſucceſs, has offered a very happy theory of the detonation of nitre. For, ſince a large quantity of dephlogiſticated air is produced from heated nitre, and this air is much more diſpoſed to promote combuſtion than the leſs pure air of the atmoſphere, it is not to be wondered at, that any inflammable ſubſtance brought into contact with nitre ſufficiently heated, ſhould be conſumed with great violence and ardor. The inflammable ſubſtance, by its great heat on the other hand, promotes the converſion of the nitrous acid into air, and the maximum of heat, relatively to the ſurface of inflamed matter and nitre in mutual contact, is quickly obtained. When that ſurface is very extenſive, as is the caſe in gunpowder, the great quantity of air, which is almoſt inſtantaneouſly generated, together with the intenſe heat, muſt occaſion a very ſtrong exploſion. The preſence of the external air is obviouſly unneceſſary.

Dephlogiſticated

Dephlogiſticated air is heavier, and phlogiſticated air is lighter than the common air of the atmoſphere.

CHAP. II.

Of Fixed Air.

IF any native calcareous earth, as chalk, marble, lime-ſtone, ſea-ſhells; or mild fixed alkali, or magneſia, be expoſed to violent heat in a retort, an elaſtic fluid is expelled, which is improperly termed fixed air. If an acid be added to any of theſe ſubſtances, an ebullition ariſes, from the eſcape of this fluid in the form of bubbles. The uſual method of obtaining fixed air for experimental purpoſes, is, by immerſing chalk in water, rendered ſour by the addition of a ſmall quantity of the vitriolic acid. Calcareous earths in general contain more than one-third of their weight of fixed air.

Fixed air is in the higheſt degree noxious; immediately extinguiſhing a candle, and producing almoſt inſtantaneous death to the ani-

mal that breathes it. It is heavier than any other kind of air, being in the proportion of 157 to 100 to the weight of atmospherical air, and is readily imbibed in water, to which it communicates an acidulous taſte, which is not unpleaſant. It does not exhibit many proofs of acidity while in its elaſtic ſtate, but is, however, ſufficiently ſo to change the color of blue ſtained paper. The criterion by which it is diſtinguiſhed is that of combining with, and precipitating the lime contained in lime-water, which by that means is rendered mild, and capable of again effervescing with acids, as has already been explained in ſpeaking of the properties of calcareous earth.

A great quantity of fixed air is emitted by ſubſtances in the ſtate of vinous fermentation. It is likewiſe emitted from bodies while they undergo the putrefactive, and, probably, during the acetous fermentation. The upper part of the large vats in brew-houſes, which are partly filled with fermenting liquor, is almoſt entirely occupied by fixed air, which, on account of its great ſpecific gravity, does not readily eſcape. It is particularly amuſing

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to make experiments with this large quantity of inviſible fluid, whoſe properties are ſo different from common air. Candles, or lighted paper, are inſtantly extinguiſhed by dipping into it; and water in a ſhallow diſh, which is held near the ſurface of the fermenting liquor, ſoon becomes impregnated with fixed air, and acquires the ſparkling appearance and briſk taſte which is obſerved in ſome mineral ſprings. A ſmall quantity of gunpowder being exploded in this atmoſphere of fixed air, the ſmoke diffuſes itſelf without riſing out of its confine: and by this means the body of fixed air may be rendered viſible, and its upper ſurface thrown into waves by agitation. But the moſt ſtriking method of performing experiments with fixed air is, to lade it out by means of veſſels, like water, or any other denſe fluid. Nothing can be more ſingular than this action, of pouring from one veſſel to another, where nothing appears that is thus poured; and to ſee, nevertheleſs, a candle inſtantly become extinct, an animal die in a few ſeconds, and an alkali made to cryſtallize, when they are put into this ſecond jar, which does not ſeem to contain any thing.

Fixed

Fixed air appears to be a peculiar acid, whoſe affinity to water is too ſmall to admit of exhibiting it in a denſe concentrated form. It ſeems to pre-exiſt in calcareous earths, and ſimilar bodies, from which it is obtained, and which may be again reſtored to a mild ſtate by re-combining with it. But it may, perhaps, be produced by fermentation from bodies in which it did not previouſly exiſt as a principle. It may be ſuſpected, that fixed air is the acid part of pure air, combined with phlogiſton; for it is abundantly produced by the deflagration of nitre with charcoal; whereas a dephlogiſticated air would have been produced if the nitrous acid had been heated with an earth not containing phlogiſton. Small portions of fixed air are obtained during the proceſſes for procuring dephlogiſticated air.

Several ſaline ſubſtances afford fixed air; and it may, as an acid, be combined with alkaline, earthy, and, perhaps, metallic baſes, ſo as to form neutral ſalts. It is ſaid that Mr. *Achard* of *Bale* has procured true cryſtals as hard, and of the ſame ſhape as native rock cryſtals, by applying fixed air in a certain manner, and by a very ſlow operation to ſome earthy matter.

A heavy

A heavy and noxious air, which by its properties ſeems to be fixed air, is found in ſome caverns, and not unfrequently in mines. The coal-miners call it choke-damp. The Grotto del Cano in Italy is a dry cave, which penetrates about twenty feet into the ſide of a mountain, and has for ages been covered at the bottom with a ſtratum of fixed air, which inſtantly extinguiſhes candles, and kills animals which hold their heads down. All the ſparkling mineral waters contain fixed air, and it is to this fluid that beer, cyder, champagne, and ſimilar liquors, owe their briſkneſs and pungency.

Liquors, containing fixed air, are remarkably antiſeptic. The impregnation of water with fixed air is therefore a matter of conſiderable importance, as it may furniſh one of the beſt remedies for that terrible diſorder the ſea-ſcurvy. The cheapeſt method of performing this is by means of a bladder, in the neck of which is fixed a perforated cork. Fig. 135. A is a bottle, containing the effervеſcing mixture of chalk, or marble, and water rendered acid by the affuſion of oil of vitriol. B is an empty bladder, in the neck of which is

faſtened a perforated cork, which in the figure is likewiſe inſerted in the neck of the bottle A. The fixed air generated by the effervescence muſt therefore paſs through the cork, and diſtend the bladder. While the bladder is thus filling, the operator fills the bottle C with water, and inverts its neck into the baſon F, which likewiſe contains a ſmall quantity of water. This may eaſily be done without any eſcape of the water from the bottle, if the neck be cloſed by means of a card, which may be withdrawn after the immerſion. The bladder being filled, muſt be withdrawn from the bottle A, and a bent tube E inſerted in the perforation of the cork, by means of which the fixed air may, by preſſing the bladder, be driven into the upper part of C, the diſplaced water ſubſiding at the ſame time into the baſon. The tube muſt now be withdrawn, and the bladder repleniſhed as before, from the bottle A; during which time the bottle C muſt be agitated, care being taken that its mouth be continually under the ſurface of the water. By this means the greateſt part of the fixed air will be very quickly imbibed by the water, which conſequently will

riſe

riſe into the bottle as before. The operation may be again repeated till the water has imbibed a quantity of fixed air exceeding its own bulk; at which period it will be found to exceed the beſt Pyrmont water in briſkneſs and pungency.

But the moſt effectual and elegant method of impregnating water with fixed air is by the apparatus delineated fig. 136. It conſiſts of three glaſs-veſſels; the lower C has two necks, D and H; the former of which is cloſed with a ground-ſtopper. The ſecond veſſel B is fitted into the neck H of the lower veſſel by grinding; and in the lower neck of B is a valve, contrived by means of a plano-convex lens, moveable between two perforated ſtoppers, as in the large repreſentation, fig. 137. The upper veſſel A, which terminates at bottom in a tube G, is likewiſe fitted by grinding into the neck I of the middle-veſſel, and is cloſed at top by a conical ground ſtopper F. The effervеſcing materials are put into the lower veſſel C, the middle veſſel B is filled with the water to be impregnated, and the whole apparatus is put together as in the drawing.

drawing. The fixed air paſſes through the valve at H into the upper part of the veſſel B, and diſplaces a quantity of water, which riſes through the tube G into the veſſel A, the common air in A lifting up the conical ſtopper F, and eſcaping. When the water in B has ſubſided below the orifice of the tube G, it can no longer be impelled into A, but a part of the fixed air riſes inſtead, and by expelling the greateſt part of the remainder of the common air, occupies the upper part of the veſſel A. Thus, then, the contained water is expoſed for a long time to a ſurface of fixed air, without any communication with the atmoſphere. The effervеſcing materials may be occaſionally renewed at the aperture D, and the impregnated water may be taſted or drawn off by the glaſs cock E. If the veſſels be not agitated, it is ſeveral hours before the water acquires its utmoſt impregnation.

The colder the water, provided it be not congealed, and the greater the preſſure it ſuſtains, the greater quantity of fixed air may be abſorbed. Water gives out its fixed air either by boiling or by being placed in the vacuum

vacuum of an air-pump. Freezing likewiſe extricates the fixed air from water, and it gradually eſcapes by mere expoſure to the atmoſphere.

CHAP. III.

Of Inflammable Air. Of Nitrous Air, and the Method of diſcovering the Purity of the Atmoſphere.

A SPECIES of air is frequently generated in coal-mines, which is inflammable. It is much lighter than common air, and therefore hovers near the top of the mine, ſo that a candle may often be carried with ſafety near the ground, which, if raiſed to the height of a few feet will burn with an enlarged flame, and ſometimes ſet fire to a vaſt maſs of inflammable air. In this laſt caſe the exploſion produces very terrible effects.

The air emitted by ſtirring the mud at the bottom of ſome ſtanding waters has been found to be inflammable. Putreſcent animal matters emit this fluid, as has been obſerved in church-yards, houſes of office, and ſuch like

like places, and the *flatus alvi* of animals is inflammable. The upper part of caſks filled with water from the Thames, and ſeveral other rivers into which much fermentable matter is waſhed, contains inflammable air after having remained cloſed for ſome months, as is well know to ſea-faring people. And the ignis fatuus, or Will-with-the-wiſp, is thought to be the inflammable air which is emitted from marſhy places, and kindled by electricity.

Inflammable air is obtained by diſtillation from wax, pitch, amber, coals, and many other phlogiſtic ſubſtances; and the quantity produced is much greater when the heat is ſuddenly applied. The flame, which accompanies combuſtion in moſt inſtances, ſeems to be produced by the generation and conſumption of this fluid. It is not eaſy in the preſent ſtate of our knowledge to determine what occaſions the difference between inflammable and phlogiſticated air. Perhaps the phlogiſton in the former may be more weakly united to its baſe, and therefore be better adapted to form that ſudden union with pure air in which combuſtion ſeems to conſiſt.

The

The moſt convenient method of procuring inflammable air is by the ſolution of metals. If iron, zinc, or tin, in ſmall pieces, or filings, be covered with a ſufficient quantity of diluted vitriolic, or marine acid, in the retort C or E, fig. 134. and a candle be applied to the bottom of the retort, the ſolution will be made with conſiderable ebullition, and inflammable air will paſs into the jar B or F.

Like all other inflammable matters, this air requires the preſence either of pure air, or of nitrous acid, to enable it to burn. Gunpowder may be fired in, or the electric ſpark may be paſſed through, a quantity of inflammable air, without producing any conſiderable alteration; but if the inflammable air be mixed with a certain quantity of common air, an exploſion is ſure to follow in either caſe. Judging by the ſound of the exploſion, an equal part, or rather more, of atmoſpherical air, is neceſſary for the inſtantaneous combuſtion of the inflammable air. Any conſiderable deviation from this proportion cauſes the exploſion to be leſs. If a candle be applied to the mouth of a bottle containing inflammable air, that part which is in the

neck, being mixed with common air, catches fire, and the whole burns ſilently away, the external air probably maintaining the combuſtion by ruſhing into the bottle. But if a mixture of dephlogiſticated and inflammable air be fired, the exploſion is aſtoniſhingly ſtrong.

Inflammable air is inſtantly fatal to animal life. It is the lighteſt fluid yet obtained on the ſurface of the earth in the mean temperature of the atmoſphere; being eleven times lighter than common air, or 8800 times lighter than water. Notwithſtanding which, its refractive power on the rays of light is rather greater than that of common air.

If the nitrous acid be applied to iron, copper, mercury, ſilver, biſmuth, or nickel, or, in general, to any kind of inflammable ſubſtance; or, if aqua regia be applied to gold or regulus of antimony, an elaſtic fluid is produced, which is known by the name of nitrous air.

A very remarkable phenomenon takes place upon the mixture of nitrous air with the common atmoſpherical air. Immediately upon their junction, a turbid redneſs appears, which is accompanied with heat. This is evidently ſimi-

lar

lar to the effervescences of dense fluids; and when it has ceased, the bulk of air is found to be phlogisticated and diminished. The diminution of the whole mixture does not consist of an equal quantity of each kind of air, but the respirable air is diminished about one-fourth, and a quantity of nitrous air disappears, which is necessary to produce that effect. If to a given quantity of common air be added nearly half its bulk of nitrous air, the whole quantity will be diminished to three-fourths of the original bulk of common air, and any farther addition of nitrous air will only produce an equal increase of the bulk without any other effect. But if, on the contrary, a small quantity of common air be added to a larger mass of nitrous air, the whole bulk, after the effervescence, will always be greater than the original bulk of nitrous air. In these experiments it therefore appears, that the diminution of the common air is always a proportional part of its bulk; but that the diminution of the nitrous air bears no relation to its own bulk, but is the absolute subtraction of a quantity which is in proportion to the quantity of common air. It follows consequently, that if

the nitrous air be inſufficient, or only equal, to produce the whole diminution, it will intirely diſappear; and, if it be in any quantity more than ſufficient, the quantity which diſappears will nevertheleſs be in all caſes the ſame. In order then to diſcover the quantity of the diminution, it is not neceſſary to employ the preciſe quantity of nitrous air which is neceſſary to ſaturate the common air, but only to add a known quantity which is known to be more than ſufficient.

Dr. Prieſtley having found that this diminution, by means of nitrous air, is of the ſame nature as its diminution by other methods, has very happily applied it as a teſt of the ſalubrity of the different ſpecimens of reſpirable air. For we have already remarked, that air, which is rendered completely noxious by any one proceſs, cannot be farther diminiſhed by any other; and in the application of this teſt, he found, that the quantity of the diminution is always greateſt in thoſe airs which are the moſt proper for reſpiration and combuſtion; that is to ſay, the moſt dephlogiſticated. Several inſtruments have ſince been invented for the purpoſe of making extempo-

raneous

raneous experiments of this nature, and are called eudiometers; but the original method of the inventor has the advantage of ſimplicity, and is eaſily put in practice. To find the purity of the air at any place, nothing more is required than to fill a bottle with water, which being poured out at the given place, is replaced by an equal bulk of air that may be corked up, and carried to any diſtance. AB, fig. 138. is a glaſs-tube, cloſed at A, and open at B. Its ſurface is graduated into equal parts by a diamond, to any degree of exactneſs. This being filled with water, and inverted perpendicularly in the tub A, fig. 134. a certain meaſure of the air to be tried, is poured into it, and an equal meaſure of nitrous air is afterwards added. By means of the graduations it is eaſy to determine the quantity of the diminution, which may be known to any degree of exactneſs, by increaſing the length of the tube, and conſequently of the diviſions relatively to its contents. Dr. Prieſtley, in ſpeaking of the diminution, expreſſes himſelf conciſely in integers and decimal parts. Thus, if a mixture of equal meaſures of nitrous and reſpirable air, after the

efferveſcence, be diminiſhed, ſo as to occupy no more than the ſpace of one meaſure and one-tenth, he ſays, the meaſure of the teſt is 1.1. But when the air is exceedingly dephlogiſticated, he adds a greater quantity of nitrous air.

If the purity, of any given portion of air, be as the diminution it ſuffers by phlogiſtication; and if the quantity of nitrous air required to ſaturate it be likewiſe in the ſame proportion, the purity of air, tried by nitrous air, will always be in the direct proportion of the diminution of the whole mixture, provided the quantity of nitrous air added be more than ſufficient to ſaturate it. That air is the pureſt which produces the greateſt effects during the time of its phlogiſtication; namely, that in which, ceteris paribus, animals live longeſt, or the greateſt quantity of a combuſtible body is conſumed.

Nitrous air is thought to conſiſt of the nitrous acid, rendered permanently elaſtic by combination with phlogiſton. It ſeems therefore to differ from inflammable air only in the nature of its acid; and when mixed with common air the phlogiſton unites with the latter.

latter. The nitrous acid conſequently precipitates in its proper form, occaſioning the turbid redneſs, and communicating an acidity to the water, over which the experiment is repeatedly made.

Nitrous air is perfectly noxious both to animals and vegetables, and is incapable of maintaining combuſtion. It unites with water, and many other fluids, and produces very curious and intereſting appearances, which the limits of this treatiſe do not permit us to enlarge on. It is antiſeptic, and is ſpecifically lighter in a ſmall degree than common air.

CHAP. IV.

Of Vitriolic Acid Air, Marine Acid Air, Vegetable Acid Air, Fluor Acid Air, Alkaline Air, and the Vapor of Nitrous Acid.

THE vitriolic acid, applied to charcoal, oil, or other inflammable ſubſtance, may be volatilized by heat, and converted into a noxious air, which is diſtinguiſhed by the name of vitriolic acid air. This air is readily combined with water, to which it gives the properties of the volatile or ſulphureous vitriolic acid. It is neceſſary therefore, in experiments with this kind of air, to uſe the apparatus in which quickſilver is ſubſtituted inſtead of water. The method of obtaining the vitriolic acid from ſulphur ſeems to be nothing elſe than the impregnating water with this kind of air.

It is remarkable, that the concentrated vitriolic acid, which produces vitriolic acid air, when applied to ſeveral metals, ſhould, when diluted, produce a very different kind of air from the ſame metals, namely, inflammable

mable air. It is worth enquiry to diſcover what the produce would be at an intermediate ſtrength of the acid.

This air is heavier than common air, and extinguiſhes flame. It diſſolves camphor, deprives borax of its water of cryſtallization, and vitiates common air.

If the marine acid be expoſed to heat, it volatilizes in the form of air, not being condenſible by mere cold. This termed the marine acid air, and the marine acid is nothing elſe than water more or leſs impregnated with it. The cheapeſt and beſt method of obtaining this air is by diſtillation from common ſalt with the vitriolic acid, as is uſual in procuring the marine acid. Common ſalt being put into the bottle C, fig. 134. a ſmall quantity of vitriolic acid is to be added, which, attaching itſelf to the alkaline baſe, diſengages the marine acid in form of air. In the open air this acid air appears in the form of white fumes, which, probably, are formed by its combination with the vapors in the atmoſphere; but the bent tube D being inſerted in the bottle, and its other end beneath a jar filled with quickſilver, the air riſes to the upper

upper part perfectly tranſparent and clear. In the beginning of this diſtillation it is not neceſſary to apply heat.

The marine acid, which is obtained by impregnating water with this air, is much ſtronger than any which is procured by the uſual method of diſtillation. For, as the proceſs is uſually managed, the diſtillers ſuffer a very conſiderable part of the acid to eſcape in the form of air, for want of applying water with which it might combine. But this error begins to be attended to by chemiſts.

Marine acid air is heavier than common air, and extinguiſhes flame. It diſſolves ice as rapidly as a hot fire. It decompoſes ſulphur, white vitriol, alum, and nitre, and therefore ſeems to be ſtronger with reſpect to affinity than the vitriolic and nitrous acids. Perhaps the great affinity between this air and water may neutralize or ſaturate it ſo far in its denſe ſtate, as to make it ſeem weaker than thoſe acids. It acts upon moſt phlogiſtic ſubſtances, and becomes converted into inflammable air. Many fluids imbibe it, and exhibit phenomena which deſerve to be conſidered.

The

The concentrated acetous acid affords an air by heat which extinguiſhes a candle. In ſome reſpects it reſembles the vitriolic acid air, but differs from it in ſeveral eſſential particulars.

By diſtillation with oil of vitriol from the minerals called fluors, but more generally known by the name of *Derbyſhire* ſpar, is obtained an acid air, which may be confined by quickſilver. When hot, it corrodes glaſs. Its moſt remarkable property is that of forming a ſtony film or cruſt with water. For a great part of this air is readily imbibed by water, at the ſame time that a ſtony matter is precipitated, and forms an encruſtation on the ſurface. This encruſtation is ſoon broken by the preſſure of the atmoſphere, which forces the water upwards into the jar, as the air is diminiſhed by abſorption, but the water which ruſhes through the interſtices is immediately covered with a new film; and ſo on ſucceſſively till the whole air has intirely diſappeared, the water thereby becoming impregnated with a very volatile acid. This air is called fluor acid air.

Water

Water impregnated repeatedly with this acid, and freed from the earthy cruſt, being heated, was found to yield air, which, by every examination, appeared to poſſeſs all the properties of vitriolic acid air.

For theſe, and other reaſons, Dr. Prieſtley is induced to think, that the fluor acid is not a particular acid, but is the acid of vitriol, charged with as much phlogiſton as is neceſſary to give it the form of air, and alſo with much of the earthy matter of the fluor. This air extinguiſhes a candle.

Volatile alkali may be rarefied into air by heat, which is diſtinguiſhed by the name of alkaline air. It muſt here be remembered, that mild or concrete alkali, as containing fixed air, is leſs proper for the purpoſe than the cauſtic alkali. For the ſake of cheapneſs, ſal ammoniac and quick-lime ſlaked, may be put in the retort, and the produce by heat will be the volatile alkali, as has formerly been obſerved, when ſpeaking of that ſubſtance.

Alkaline air readily and copiouſly combines with water, with which it forms a ſtrong volatile alkaline ſpirit. It diſſolves ice as quickly

quickly as the moſt intenſe heat. A very pleaſing effect takes place, if it be mixed with any acid air. The two fluids immediately unite, forming a neutral ſalt, whoſe aggregation appears like a white cloud, filling the receiver; and in ſeveral inſtances, when the quantities of each are ſuch as exactly to ſaturate each other, the whole elaſtic fluid diſappears by the union. With fixed air it forms a concrete ſalt, in oblong ſlender cryſtals; with vitriolic acid air it forms vitriolic ammoniac; and with marine acid air, common ſal ammoniac.

Alkaline air is ſlightly inflammable. The electric ſpark, taken in alkaline air, produces inflammable air; and the quantity or bulk is three times that of the alkaline air. That a ſpecies of air, which is totally ſoluble in water, ſhould, by the electric ſpark, be rendered inſoluble, together with a very conſiderable change in its other properties, is a circumſtance which well deſerves to be enquired into; as its explanation cannot fail to throw great light on the nature of theſe ſubſtances.

There is little reaſon to doubt but that the nitrous acid might be exhibited alone in the form

form of air; if any fluid could be diſcovered by which it might be confined. But the vapor of nitrous acid unites with water and with oils, and corrodes quickſilver. Water impregnated with this vapor is converted into a ſpirit of nitre, which gradually emits a great quantity of nitrous air. Oils impregnated with it emit phlogiſticated air. The vitriolic and marine acids may be impregnated with this acid vapor. The vitriolic acid, when ſaturated, becomes cryſtallized, and the fluid part is found to be the nitrous acid. But the marine acid is converted into the beſt aqua regia, which afforded nitrous air by heat. The impregnated vitriolic acid afforded no air.

We here conclude the preſent ſection without attempting to ſpeculate upon a ſubject, which, though of late years it has been followed with an attention equal to its importance, and has been enriched with many capital diſcoveries, may ſtill be ſaid to be in embrio. The greateſt advantages may be expected to ſcience from an examination of ſubſtances in a ſtate of ſuch extreme diviſion as is neceſſary to produce the form of air. Many

have

have already been obtained, and the numerous labourers at preſent engaged in this ample, and, till lately, unexplored region of chemiſtry, encourage us to hope for great things. Prudence and caution ought therefore to correct and guard our imaginations. A few years will probably enable us to look back on the preſent infancy of our knowledge, and ſee the futility of thoſe theories which we are too apt to regard as ſome of the greateſt efforts of the underſtanding.

BOOK III

SECT. III.

Of Electricity.

CHAP. I.

Of Electricity; and the Relations that ſubſiſt between it and different Bodies.

ELECTRICITY is that branch or department of natural philoſophy, in which the appearances occaſioned by the motions or action of the electric matter are explained: it is alſo uſed to imply the electric matter itſelf.

The uſual method of procuring or exciting electricity is by rubbing a tube or cylinder of glaſs with the hand, or a rubber of ſoft

leather. If a tube of an inch and half in diameter, and about three feet long, be rubbed, by drawing the hand, or a rubber of leather, from one end to the other, it will become electric; ſmall flaſhes of divergent flame, ramified ſomething like trees bare of leaves, will dart into the air from many parts of the external ſurface of the tube, to the diſtance of ſix or eight inches, attended with a crackling noiſe; and ſometimes ſparks of more than a foot in length will fly along the tube to the rubber. While the tube is in this ſtate, it attracts light bodies, and immediately afterwards repels them; and does not again attract them until they have touched ſome non-electric body. If this non-electric body be near the tube, the light body will be alternately attracted and repelled for many viciſſitudes. If any non-electric body be preſented near the tube, the electric matter will fly, in the form of a ſpark or ray of fire, from the tube to the non-electric.

With reſpect to the electric matter, all bodies may be divided into two claſſes, electrics and non-electrics. Electrics are thoſe bo-

dies, any part of whoſe ſurface may be rendered electrical by friction or otherwiſe, without communicating the ſame kind of electricity to any other part. Non-electrics are thoſe bodies which cannot be rendered electrical by friction with each other; and if electrified by other means at any part, the whole of the body exhibits the ſame kind of electricity. The latter are termed conductors. The only unequivocal diſtinction between theſe two claſſes, or at leaſt the ſtrongeſt and moſt remarkable, is, that the non-electrics conduct the electric matter through their ſubſtance without any ſenſible reſiſtance, whereas electrics do not conduct. In the uſual temperature of the atmoſphere, metallic ſubſtances, water and charcoal are conductors: all other bodies are non-conductors.

A non-electric, which is ſupported by electric bodies, is ſaid to be inſulated, provided it do not touch the earth, nor any one of a ſeries or ſet of non-electrics in contact, which touch the earth in any part of the ſeries.

If the excited tube be brought near enough to an inſulated conductor to give ſparks to it, the

the conductor will be electrified, and exhibit the ſame ſigns of attraction and repulſion; and if the finger, or any other uninſulated non-electric, be brought near, the conductor will give one ſtrong ſpark, and loſe its electrization. This follows from the nature of a conducting ſubſtance; for when the electric matter leaves the inſulated non-electric, it is readily conducted to the place of exit, and therefore eſcapes all at once; whereas in the tube, when a ſpark is drawn, it is much ſmaller, as conſiſting only of ſo much electric matter as is within the ſtriking diſtance from the finger: this muſt therefore be repeated at every other part of the tube before the whole of the electric matter can be drawn away.

No experiments have yet been diſcovered to ſhew in what particular the difference between electrics and non-electrics conſiſts; but whatever the conducting power may depend on, it ſeems to be governed by the heat of the body: glaſs, reſin, baked wood, and many other non-conductors, are conductors when made very hot. Now, as we ſee like phenomena produced in different bodies with very different degrees of heat,

for example, a fluid ſtate is produced in quick-ſilver by the leaſt heat, in ice by a greater, in butters, reſins, ſulphurs, metals, and glaſs, by degrees ſtill increaſing, and very different, why may it not be conjectured, till deciſive experiments are exhibited, that the diſpoſition to conduct electricity is produced in metals by the leaſt heat, in water by a greater, and in reſins and glaſs by degrees ſtill greater? and conſequently that there is a certain degree of heat at which a given body may be ſaid to be at the medium between perfect conducting, and non-conducting, above which degree it becomes a conductor, and beneath, a non-conductor. If this be allowed, it muſt follow, that conductors are bodies whoſe electric or non-conducting ſtate is placed at a degree of heat far below that which is underſtood by temperate, and that non-conductors are thoſe whoſe conducting ſtate is placed at a degree of heat far above that of temperate.

That electricity is real matter, and not a mere property, is evident, becauſe it is itſelf poſſeſſed of properties. When it jumps from one body to another, it divides the air, and puts

puts it into thoſe undulations in which ſound conſiſts. It emits the rays of light in every direction, and thoſe rays are variouſly refrangible, and colorific, as other light is. Now, as light has long been acknowledged to be matter, it is contrary to reaſon and experience to ſuppoſe, that the thing which emits it is not likewiſe material. Neither are the other ſenſes unaffected at its preſence; its ſmell is ſtrongly phoſphoreal or ſulphureous, inſomuch, that when the air of a room is rendered highly electric, many perſons have complained of an unuſual and diſagreeable ſenſation in the head from that cauſe. The ſenſe of feeling is a witneſs of its preſence, not only from the ſparks, which, when received from the conductor of a powerful machine, are very pungent, and will paſs through two or three perſons ſtanding on the ground, but alſo from the ſhock, whoſe effects are to be deſcribed: and a ſtream of the electric matter received on the tongue has an evidently ſubacid taſte, which remains ſome little time after.

As the exciting a tube is very laborious for the operator, and the electricity procured by

that means is ſmall in quantity, globes or cylinders are much more uſed. Theſe, by a proper apparatus, are made to revolve on their axes after the manner of a grindſtone, and a rubber of leather is applied to the equatorial parts of the revolving glaſs, which become electrical by the friction. The electricity of the globe is received by a metallic conductor, which is inſulated by a glaſs-foot, or ſupporter. This conductor being thus conſtantly electrified, and being at the ſame time ſteady and motionleſs, is much better adapted for making experiments than the globe itſelf.

A cylinder or globe thus adapted to revolve on its axis, and provided with a rubber and an inſulated conductor, is called an electrical machine. The contrivances for the revolution of the cylinder or globe vary in different machines, as likewiſe the method of inſulating the conductor. The conductor is in general ſupported by a ſtick of baked wood or glaſs, and ſometimes it is ſuſpended by ſilk-ſtrings.

CHAP.

CHAP. II.

Of Excitation; of the two different States of Electricity, and of the Effects of pointed Non-electrics.

THE excitation of electrics, rubbed againſt each other, is very ſmall. To produce any conſiderable degree of electricity, it is neceſſary that the rubber ſhould be a conducting ſubſtance, and that it ſhould not be inſulated.

If the rubber of an electrical machine be inſulated, and the conductor uninſulated by hanging on it a chain which communicates with the earth, the rubber will become ſtrongly electric by turning the globe, will attract and repel light bodies, and act in the ſame manner in almoſt every particular as the conductor when electrified in the uſual method. If of two conductors, ſeparately inſulated, one be connected with the inſulated rubber, and the other placed near the globe, ſo as to be electrified by it, they will both exhibit ſigns of electricity; but that conductor, which is electrified by the globe, will attract thoſe bodies which are

repelled by the other conductor which received its electricity from the rubber. And theſe conductors, if brought near each other, will emit ſparks, and act on each other in every reſpect ſtronger than on other bodies. If they be brought into contact, the electricity of the one will deſtroy that of the other; and notwithſtanding the electric matter appears to emanate from the globe to its conductor, the two thus conjoined will exhibit few or no ſigns of electricity.

We have hitherto ſpoken of the electric matter as paſſing from the cylinder to the conductor, but in reality the ſenſe cannot diſtinguiſh the direction in which it moves. If it be true, that the electric matter paſſes from the cylinder to the conductor, the conductor muſt, when electrified, poſſeſs a greater quantity than is natural to it; and ſince the cylinder is not excited by an inſulated rubber, it is evident that it receives its electricity from the rubber, and conſequently, unleſs the rubber be at liberty to receive an equal quantity from the earth, that is, unleſs it be uninſulated, it can part with but a very ſmall quantity to the cylinder. Still retaining the ſame ſuppoſition reſpecting

reſpecting the courſe of the electric matter, it follows that the rubber when inſulated muſt loſe a part of its natural quantity by friction with the cylinder, and conſequently a conductor communicating with it muſt be negatively electrified. It is not therefore ſo much to be wondered at, that the actions of the two conductors ſhould be contrary, and that when in contact they ſhould exhibit no ſigns of electricity; for the cylinder at the ſame inſtant that it imparts the electric matter to one conductor, exhauſts an equal quantity from the other, which is connected with the rubber. If the direction of the electric matter be ſuppoſed to be contrary to what we have aſſumed, the effects muſt ſtill be the ſame.

The circumſtance on which the prevailing opinion concerning this direction is founded is, that if the conductor, which derives its electricity from the cylinder, be made ſharp or angular at any part, which is not very near the cylinder, a diverging cone of electric light will be ſeen, whoſe vertex is the point itſelf, and the electric phenomena will be much diminiſhed. But the conductor, which

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is connected with the rubber, though its effects be equally diminiſhed by a ſimilar circumſtance, will never exhibit the cone of rays, but is only tipped at the point with a ſmall globular body of light. The cone has been thought to reſemble the ruſhing out or emitting of the electric matter, and the globe has been imagined to anſwer the appearance of the imbibing or entrance of the ſame; whence the name of poſitive electricity has obtained for that of the cylinder, and negative for that of the rubber. We ſhall uſe the terms in the ſame ſenſe, though it muſt be confeſſed, that the propriety of their application is ſtill doubtful.

If electricity be produced by the excitation of a globe or cylinder of ſulphur or reſin, the ſtates will be reverſed; the rubber will be poſitive, and the cylinder, with its conductor, will be negative. This was formerly thought to depend on the nature of the electric body, and the two ſtates of electricity were diſtinguiſhed by the names of vitreous and reſinous electricity, but it has ſince been diſcovered, that the difference ariſes from the relative ſmoothneſs of the ſurfaces of the electric body

and

and its rubber when compared with each other.

It ſeems to be a rule, that the ſmootheſt of the two bodies obtains the poſitive ſtate. Baked wooden cylinders, with a ſmooth rubber of oiled ſilk, become negative, but with a rubber of flannel poſitive. Glaſs, made rough by grinding with emery, excited with new ſoft flannel, is negative, but with dry oiled ſilk, rubbed with whiting, poſitive; but if the glaſs be ſmeared with tallow, and wiped with a cloth, then the oiled ſilk, by rubbing, becomes poliſhed, and the tube becomes negative, as at firſt; if the oiled ſilk be again rubbed with whiting, it excites a poſitive ſtate on the greaſed tube; but when the ſilk has again acquired a poliſh, the tube becomes again negative. Even poliſhed glaſs may be rendered negative by rubbing with the hairy ſide of a cat's ſkin.

The rubber in the common electrical machine is uſually covered with an amalgama of mercury and tin, and the leather is damped occaſionally. Theſe proviſions augment the excitation very much. It ſeems as if the amalgama or metallic rubber, being a perfect

conductor,

conductor, ſupplied the cylinder more readily with the electric matter than any other body. The precaution of damping is to keep the rubber more perfectly uninſulated.

It is a maxim, that bodies poſſeſſed of ſimilar and equal ſtates of electricity, repel each other; that bodies poſſeſſed of oppoſite ſtates of electricity, attract each other; and that bodies in a mean or natural ſtate are attracted by all electrified bodies whatever. But as we have no clear conception, or adequate idea, of any mechanical proceſs by which attraction may be cauſed, all our reaſoning on the ſubject muſt be not only hypothetical, but viſionary, for want of probable grounds to proceed on. Yet, if ever we ſhould arrive at an explication of this property of matter, whoſe origin at preſent is ſo little underſtood, we have great reaſon to think that it will be in conſequence of electrical diſcoveries.

Speaking of the poſitive and negative conductors, it was obſerved that electricity was emitted or imbibed at the angular or pointed parts. It is neceſſary to advert again to that particular. If the inſulated

conductor

conductor of a machine, uſually called the prime conductor, be well poliſhed, and without corners or angles, it will retain its electric ſtate very well, and will emit ſtrong ſparks upon the approach of any uninſulated conductor. If the uninſulated conductor be broad, round and poliſhed at the end, the ſparks will be ſhort and denſe, and will produce a conſiderable ſound; if the conductor be leſs broad, *ceteris manentibus*, the ſpark will be long, crooked, and leſs ſounding; if the breadth be ſtill more diminiſhed, the conductor begins to come under the denomination of a pointed body, the electric matter paſſes to it from the prime conductor, thro' a great ſpace of air with a hiſſing or ruſtling noiſe, and in a continual ſtream: a ſtill greater ſharpneſs enables the electricity to paſs over a greater ſpace, but ſilently, and nothing is ſeen but a ſmall light upon the point. If a ſimilar point iſſue from the prime conductor, and the uninſulated conductor be round and poliſhed, the ſame effects happen in like ſituations; but if both be pointed, the electricity is more readily diſcharged; and in all caſes the appearance of the electric matter at the point of the

the prime conductor will be that which is peculiar to its electricity, a large divergent cone if positive, or a small globular light or cone if negative, and the light at the point presented to the prime conductor will be distinctive of the contrary electricity. Whether a pointed conductor be electrified positively or negatively, if the nose be brought near the point during the electrization, a gentle air will be felt blowing from the point, and the sense will be affected with a sulphureous or phosphoreal smell.

The reaction of the force by which the air is put into motion, is exerted on the pointed body. This is shewn by a pleasing experiment with an electrified wire, thus; to the middle of the wire, or rather between two wires that lie in the same line, is affixed a center-cap like those used in sea-compasses, so that the wire may easily be moved on a point in an horizontal direction, as magnetical needles are; and the ends of the wire are pointed and bent contrary ways to point in the direction of the tangent to the circle described by them. Now if this wire thus suspended on a point, be insulated and electri-

fied,

fied, its ſharp ends will become luminous, and it will revolve in a direction contrary to that in which its ends are bent; or if it be ſuſpended on an uninſulated point, and brought near the electrified prime conductor, the ſame effect will follow.

Theſe are the chief phenomena that accompany the electrization of pointed conductors, and are as yet but very imperfectly underſtood. The facility with which pointed bodies emit or receive the electric matter ſeems to depend on a circumſtance which we have not yet explained, namely the diſturbance which the approach of an electrified body makes in the electric matter naturally reſiding in or near any conductor, before any communication enſues. We ſhall therefore again advert to the ſubject of points when we deſcribe that property, and in the mean time it will not be difficult to account for the other appearances on the ground of the matter of fact only, namely, that points do readily emit or imbibe the electric matter.

It may be thought ſtrange that the air ſhould iſſue *from* an electrified point, whether its electricity be poſitive or negative. We

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can eaſily conceive that the iſſuing out of the electric matter may cauſe the air to move in the ſame direction, but it appears ſtrange, that the electric matter ruſhing towards a point ſhould cauſe the air to move directly contrary, that is to ſay, likewiſe from the point. But if the circumſtance be examined more narrowly, the difficulty will vaniſh. For it is highly probable that the electric matter paſſes too ſwiftly to excite any motion in the air but that of ſonoriferous undulation; to which we may add, that, if the electric matter do act on the air to put it in motion, the air muſt react with an equal force; and therefore that a current of air blown againſt the courſe of the electric matter muſt affect its appearance, by retarding the rays and deflecting thoſe againſt which if ſtruck obliquely: the contrary to which is, by experience, known to obtain; for the luminous cones are not ſenſibly affected by ſuch treatment. The air being thus indifferent as to the motion of the electric matter, its motion may be ſhewn to depend on the eſtabliſhed principles of electricity. The point is electrified either poſitively or negatively, and the air, immediately

ately oppoſite and contiguous to the point, muſt, by the emiſſion or exhauſtion of the electric matter, become ſtrongly poſſeſſed of an electric ſtate of the ſame kind with that of the point: it is therefore repelled and replaced by other air which is alſo electrified and repelled, by which means a conſtant ſtream is produced blowing from the point, and that equally whether the electrization be poſitive or negative. And, as action and reaction are equal and contrary, the point repelling the air muſt itſelf alſo be equally repelled in the contrary direction; whence the horizontal wire above deſcribed is turned, and that always one way, namely, contrary to that in which the air is moved, or to the direction of its bent points.

CHAP. III.

Of the Courſe of the Electric Matter through the common Air, and through Air very much rareſied, with a Deſcription of an Electrical Machine.

THE air, being a non-conductor, muſt be claſſed among electric bodies, and the prime conductor of an electrical machine being ſurrounded with air retains its electric ſtate much better than it would do without that circumſtance. For the electric matter cannot paſs to or from the conductor with the ſame facility as if this impermeable ſubſtance were not interpoſed.

When air is ſpoken of as impermeable and electric, it muſt not be underſtood as being perfectly ſo, there being perhaps no body in nature that anſwers that definition, but as being moſtly compoſed of non-conducting parts. There is always moiſture enough in the air to reſtore the natural ſtate to electrified bodies in a few hours. It is likewiſe

perme-

permeable, as all other electrics are, by the force of the electric matter which divides it or ſeparates its parts: when this happens to a ſolid electric, a hole is made through it.

Long ſparks are always crooked in various manners like lightning; the cauſe of which ſeems to be, that the electric matter paſſes through thoſe parts of the air in which the beſt conductors are found. Indeed there is reaſon to think that electricity always requires a conductor to enable it to paſs from one body to another. For if a glaſs ſyphon, whoſe legs are equal, and reſpectively more than thirty inches long, be filled with boiling mercury, and the ends inverted into baſons likewiſe containing mercury, a double barometer will be formed whoſe upper or arched part will be abſolutely void of air. Then if one of the baſons be inſulated and electrified, the electricity will not paſs from the mercury in one leg, through the void, to that in the other; but upon admitting a ſmall bubble of air it is immediately ſeen paſſing through the vacant ſpace in the form of bright flaſhes of flames. In the vacuum of the air-pump the electric matter will paſs and appear luminous

between conductors, how diſtant ſoever, forming a beautiful appearance, that very much reſembles the northern lights or aurora-borealis. It ſeems, on conſideration of theſe circumſtances, that the electric matter could not paſs through the abſolute void, for want of a conductor, but that the conducting part of the air introduced, anſwered the purpoſe, while the reſiſtance of the electric part, being very ſmall, on account of the rarefaction, ſuffered it to paſs from one conductor to another through much greater ſpaces than it can paſs through in the open air.

This opinion is ſomewhat more confirmed by the obſervation that the electric matter forces conducting bodies into its path. If a drop of water be laid on the prime conductor, very long ſparks may be drawn from it, the drop will aſſume a pointed or conical ſhape, and wet bodies which are held near it: a proof that the water is thrown off. If the ſame experiment be made with melted ſealing-wax, the appearance is very peculiar and amuſing. The ſealing-wax muſt be dropped on or ſtuck to the ſide of the prime conductor, and afterwards melted with a candle; then if

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the conductor be positively electrified, the drop of wax becomes pointed and shoots an almost invisibly fine thread into the air to the distance of more than a yard. This thread is electrical, and would probably be longer, were it not for the sudden cooling of the wax. Whether the same effect would follow on negative electrization is worth the enquiry, but the want of a convenient and strong negative power has prevented the writer of this work from trying it. It is observable that the long sparks abovementioned, with the drops of water, are not seen when the drop is negatively electrified, a light only appearing at the point of the drop. But as the methods used in the experiment did not produce a negative state as strong as the positive one, the constancy of the effect requires to be confirmed by more favorable experiments. Thus much is fact, that the same drop of water which when laid on a cylinder of metal, and connected with the positive prime conductor, emitted sparks five or six inches long, did not produce the least spark when uninsulated and held near the prime conductor, but drew off the electricity exactly as a metallic point would have done.

Thus much of the properties of electric and non-electric bodies being premiſed, we ſhall be able to give an intelligible account of the conſtruction of the electrical machine. As the forms of glaſs cylinders, globes or ſpheroids, the mechaniſm by which their rotation is effected, the poſition, ſhape and matter of the rubber, and the form and mode of inſulating the prime conductor, are all ſuſceptible of great variations, ſo the conſtruction of electric machines has been very different, according to the views and opinions of the makers.

The beſt and moſt elegant machine (fig. 139.) conſiſts of a pillar of mahogany, a, ſtanding upright on three feet. This pillar divides in two places, to receive a wheel, b, in the lower part of it, and in the upper part a pulley, c, which is turned by a leathern ſtrap, d, tightened by means of a ſmall buckle. In the center of the pulley is a ſtrong iron ſpindle, turning in two firm braſs ſockets faſtened to the pillar. In one of the ſockets the extremity of the ſpindle turns upon a center, by means of a piece of iron, e, ſcrewed into it, while the other is held tight by a braſs

claſp,

claſp, which may be made to hold it cloſer, or more looſely, at pleaſure, by means of a ſcrew. The iron ſpindle is made hollow, in the form of a parallelopiped, in order to receive a piece of braſs or iron, in which the braſs cap that holds the globe, g, terminates. Theſe are exactly fitted to one another, and by this means any globe may be taken out, and another put into the machine, with very little trouble, if theſe parts be always made to the ſame pattern.

The globe has its neck cemented into a braſs cap, which terminates in a ſquare piece of iron as abovementioned.

The rubber, h, conſiſts of a hollow piece of copper, filled with horſe-hair and covered with baſil leather. This is again covered with dry oiled ſilk, which is ſewed to that edge of the leather towards which the parts of the globe move in revolving. Towards the other edge the ſilk is conſiderably longer than is neceſſary to cover the rubber, and that part of the ſilk which covers the rubber is to be rubbed with the amalgama of tin and mercury, mixed with a ſmall quantity of bees-wax and tallow. The uſe of that part of the

ſilk which hangs out beyond the ſurface of the rubber, is to prevent the electric matter from returning back to the rubber along the ſurface of the globe: for when the globe is excited, this pendant ſilk is attracted and adheres cloſely to its ſurface, and prevents thoſe returning ſparks and coruſcations which are continually emanating from, and diminiſhing the electricity of a naked globe. The effects ſeem to be more than twice as great by the uſe of this contrivance. The rubber is ſupported by a ſocket which receives the cylindrical axis of a round and flat piece of baked wood or glaſs, j, the oppoſite part of which is inſerted into the ſocket of a ſteel ſpring, i. Theſe parts are eaſily ſeparated, ſo that the rubber, or the piece of wood or glaſs which ſerves to inſulate it, may be changed at pleaſure. The rubber may be uninſulated by means of the chain k, which forms a communication between it and the ſpring; and the ſpring may be made to preſs more or leſs by the ſcrew l. It may alſo be raiſed higher or lower, to ſuit globes of different ſizes, by means of a contrivance not repreſented in the plate.

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The prime conductor, m, is a hollow veſſel, of poliſhed copper, in the form of a pear, ſupported by a pillar, and a firm baſis of baked wood, and receives its electricity by means of a long arched wire or rod of very ſoft braſs, n, eaſily bent into any ſhape, and raiſed higher, or let lower, as the globe may require. It is terminated by an open ring, in which are hung ſome ſharp pointed wires, o, playing lightly on the globe when it is in motion. The body of the conductor is furniſhed with holes and ſockets, for the inſertion of metallic rods, to convey the electricity wherever it is wanted, and for many other purpoſes convenient in a courſe of experiments. The peculiar ſhape of this conductor renders it the moſt capable of retaining its electric ſtate; for, in the common conductors, which are cylinders, with hemiſpherical ends, the electricity has a greater tendency to eſcape at the part which is moſt diſtant * from that at which it receives its electric ſtate: this therefore, being more obtuſe at the moſt diſtant part, is leſs diſpoſed to emit or imbibe the electric matter at

* Or rather, perhaps, from the excited globe:

that

that part; and conſequently, the diſpoſition ariſing from the figure being contrary to that which is produced by the ſituation, it becomes as little diſpoſed to part with its electric ſtate by that part as by any other. And if the generating curve be properly adapted, the nitency of the electric matter to influx or emiſſion muſt be equal at every point of the ſurface. The electromer, rp, was invented by Mr. Lane. It conſiſts of a ball, p, which, by means of a wire, whoſe ſurface is cut into a fine ſeries, and is inſerted through the head of a pillar of conducting matter, is carried nearer to or farther from the prime conductor, and ſerves to meaſure the diſtance to which ſparks are emitted. This diſtance is ſhewn by the diviſions on the plate r.

When negative electricity is deſired, the chain k muſt be removed from the rubber, and hung upon the prime conductor, ſo as to connect it with the table; and a ſhort braſs-rod, with a knob at the end of it, muſt be ſcrewed into a ſmall ſocket in the rubber, above the plate of baked wood or glaſs. The braſs-rod will then ſerve for a negative prime conductor; for, in this ſituation,

tion, when the wheel of the machine is turned, this rod being inſulated, together with the rubber, through which all the electricity paſſes to the globe, will receive ſparks from any uninſulated non-electric which is preſented to it, and therefore electrify negatively.

CHAP.

CHAP. IV.

Of the Electricity which is produced by bringing a Conductor near the electrified Prime Conductor; and of charging and discharging Electric Plates.

IF an insulated conductor, which is free from points, be brought within a certain distance of the prime conductor in an electric state, it will also exhibit signs of electricity of the same kind; but if those signs be removed, by taking the spark, and the conductor taken from the prime conductor, it will exhibit signs of the contrary electricity. This is a very remarkable phenomenon, but may be accounted for, if the two suppositions be admitted, viz. first, that the electric matter is attracted by conducting bodies; and secondly, that the parts of the electric matter mutually repel each other, the forces of each power being in a certain inverted ratio of the distance.

For the electric matter in an insulated and uniform conductor will then be equally dif-

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fuſed through its whole maſs, and the attraction which that conductor will exert on any maſs of electric matter preſented ab extra muſt be the exceſs of the attractive force of the body over the repulſive force of the electricity it contains. Whence a given conductor will attract the electric matter the moſt powerfully when the quantity it already poſſeſſes is the leaſt poſſible, and its attractive force will decreaſe as it becomes more ſaturated with electricity. Let two equal conductors, compoſed of like matter, be brought within a ſmall diſtance of each other, then, if the quantities of electricity they contain are equal, the attractions they mutually exert on thoſe quantities will be equal, and it will remain undiſturbed in each body. But if one conductor, A, contain more electricity than the other, B, the attractive power of B will be greateſt, and will draw the electric matter from A till an equilibrium is obtained. It follows alſo, that in a number of conducting bodies, communicating with each other, the electric matter will be every where of the ſame denſity, if the greateſt attractive force of the bodies be ſuppoſed equal; but if different

bodies

bodies be ſuppoſed to attract the electric matter with different forces, as is moſt probable, the denſities muſt vary with the forces. This may be called the natural ſtate.

To apply this to the particular inſtance above-recited, ſuppoſe the end of an inſulated conductor to be brought near the prime conductor in a poſitive ſtate, the attractive power of the firſt-mentioned conductor is greater than that of the prime conductor, yet, not being ſufficient to draw ſparks, at the given diſtance, the only effect it can produce is, to make the electric matter accumulate, and become more denſe in that part of the prime conductor near which it is preſented; by which accumulation the reſt of the prime conductor becomes leſs electrified, as experience teſtifies. This accumulated body of electricity repels, and conſequently rarefies the electric matter naturally contained in that end of the conductor, which is preſented to the prime conductor; the reſt of the fluid becomes more denſe, and the other parts, of the conductor which is preſented, exhibit ſigns of electricity; yet, as this conductor in the whole contains no more than its natural quantity, if

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the electric ſtate be taken off by drawing the ſpark, and it be afterwards removed from the vicinity of the prime conductor, it becomes negative throughout, by reaſon of the loſs of the ſpark. If a conductor be preſented to the prime conductor in a negative ſtate, the effects are reverſed, the attraction being ſtrongeſt at the prime conductor, and the accumulation being in the conductor which is preſented, it exhibits a negative ſtate, which being deſtroyed, upon removal it becomes poſitive, by reaſon of the ſpark which was given to it when apparently negative.

Theſe effects are more conſiderable the leſs the diſtance is between the two conductors; and the intercedent electric body is peculiarly affected: the manner of which may be better underſtood, by obſerving the phenomena of non-electrics, ſeparated by electrics which are leſs liable to allow the paſſing of the ſpark than the air is.

Upon an inſulated horizontal plate of metal, lay a plate of glaſs, conſiderably larger, ſo that there may be a rim of three or four inches projecting beyond the metal on every ſide. Upon the glaſs lay another plate of metal,

metal, of the ſame ſize as the former, ſo as preciſely to cover it. Electrify the upper plate, and the lower will exhibit ſigns of electricity. Continue the electrization, and the lower plate will emit ſparks to an uninſulated body for a time, and afterwards ceaſe. Separate the plates from the glaſs without uninſulating them, and the glaſs will appear to be poſſeſſed of the contrary electricity on the oppoſite ſides. That ſide which communicated with the prime conductor during the electrization will have a like electricity, and the other the contrary. Take off the electricity of the plates of metal, and carefully replace the glaſs on the lower, without deſtroying the inſulation, and alſo replace the upper plate in like manner. Then, with one end of an inſulated wire, not pointed, but rather knobbed at the ends; touch one of the plates, and bring the other end near the other plate: the conſequence will be, that a prodigious ſtrong and loud ſpark will paſs between it and the wire, the electricity of the glaſs will be diſcharged, and the plates and the wire will ſtill continue unelectrified.

An electric body whoſe ſurfaces are thus poſſeſſed of the contrary electricities, is ſaid to be charged. The inſulation of the lower metallic plate and of the diſcharging wire is not neceſſary, except for the purpoſe of drawing inferences, reſpecting the manner of charging the electric plate. If the electricity of the prime conductor be very ſtrong, the diſcharge will ſometimes be made by a ſpark from the one metallic plate to the other, over the ſurface of the glaſs which projects on every ſide; and if the glaſs plate be thin, in which caſe it admits of a much higher charge, the diſcharge will be made through its ſubſtance. Glaſs as thick as one-eighth of an inch, may be penetrated by this means, one or more holes being made where the electric matter has paſſed, in which holes the glaſs is pulverized, and may be picked out with a pin.

The greater the ſurface of the glaſs, the greater quantity of electricity it will contain, the ſame denſity being ſuppoſed. But a given machine will not ſuperinduce ſo ſtrong an electric ſtate on a large plate as a ſmall one: the reaſon of which ſeems to be the different ſpaces of time required in the charging,

conjoined with the different magnitudes of the ſurfaces at which the electricity is communicated to the air. If there were no eſcape of the electric matter during the time of charging, the times will probably be as the ſurfaces of the plates, equal thickneſſes being always ſuppoſed; and if two plates were equally charged, the eſcape would perhaps be likewiſe as the ſurfaces. Theſe being premiſed, the whole eſcape will be as the time of charging, and the ſurfaces of each conjointly, that is, becauſe the times are as the ſurfaces, in the duplicate ratio of their ſurfaces directly. Hence it appears that the eſcape in plates, that increaſe in ſize, approaches rapidly and continually nearer to the quantity of electricity ſupplied by the machine, and that the more powerful machine, by diminiſhing the time of charging, will charge higher in the inverſe proportion of the time, ſo much eſcapement being ſaved. It muſt be confeſſed that the ſuppoſitions not being accurate, the ratios are only nearly true, yet this way of conſidering the ſubject ſerves to indicate the cauſes, though not ſtrictly to meaſure the effect.

From

From the above related experiment, of ſeparating the glaſs from the plates of metal, it is ſhewn that the ſurplus of the electricity on one ſurface, is preciſely equal to the deficiency on the other; for if it were otherwiſe, the plates and the diſcharging wire would become poſſeſſed of the predominating electricity. It alſo ſhews that if the theory of poſitive and negative electricity be true, electric bodies muſt contain the electric matter, for the electric ſtates are evidently on the ſurfaces of the glaſs independent of the metal: now though we can conceive that a poſitive ſtate may be ſuperinduced by an accumulation of electricity on one ſurface, yet it is abſurd to ſuppoſe that the electric matter can be emitted and exhauſted from the other ſide, if it did not exiſt there, previous to ſuch emiſſion and exhauſtion. From this we have ground to conclude that all bodies, as well electrics as non-electrics, do attract the electric matter, but that electrics, being ſo conſtructed as not to admit it into their ſubſtance, as non-electrics do, do condenſe it upon their ſurfaces, and at all times hold a great quantity ſo condenſed. And if the quantity of electri-

city be increaſed or diminiſhed on one ſide, the electricity on the other ſurface muſt be rarefied or condenſed in conſequence of the diminution or increaſe of the whole attractive force of the body, as explained in the beginning of this chapter. The effects will alſo be more conſiderable the leſs the diſtance is between the two ſurfaces.

It is not poſſible to charge an electric plate by inducing an electric ſtate on one of its ſurfaces, unleſs the other be at the ſame time ſufficiently near to an uninſulated non-electric to aſſume the contrary ſtate by emitting or receiving the electric matter.

If a plate of glaſs be laid upon an uninſulated plate of metal, the upper ſurface may be rendered electric by friction, or by applying an electrified body ſucceſſively to its parts. This electricity may be taken off by touching the upper ſurface with an uninſulated metallic plate of the ſame dimenſions as that upon which the glaſs is placed, but will not be entirely taken off, becauſe the communication between the two ſurfaces in this method is not perfect, and becauſe the metal cannot, by ordinary means, be brought into actual con-

tact

tact with the glaſs. The ſmall quantity which remains, produces an effect which has been miſtaken for a perpetual electricity. For if a plate of metal, to which a glaſs handle is affixed, be laid upon the glaſs, this ſmall quantity of electricity will influence the metal, and, without actually communicating the electric matter, will cauſe it to exhibit a ſimilar ſtate, upon the principle explained at the beginning of this chapter. If this be taken off, by drawing the ſpark, and the metal then removed, by means of the glaſs handle, it will be found poſſeſſed of the contrary ſtate of electricity, and another ſpark may be produced. The metal plate may be then again applied to the ſurface of the glaſs, and the proceſs again repeated, and ſo on for a prodigious number of times, without any ſenſible difference in the event. For the electricity at the ſurface of the glaſs being almoſt in the natural ſtate, as to condenſation, does not diſappear for a very long time, and the very near approach of the metal enables it to produce the ſame effect as would be obtained at a greater diſtance from a ſtronger electricity. This is made obvious by bring-

ing the metallic plate near the ſurface of the glaſs before its firſt ſtrong electricity is taken off, for the ſame event is perceived at the diſtance of four, five or ſix inches as in the former caſe was produced by contact.

The vapors of the atmoſphere are continually attaching themſelves to the ſurface of cold glaſs, and by that means deſtroy the electricity. Sulphur, wax or reſin, being leſs ſubject to this, retain their electric ſtate much longer. A plate of glaſs or wood, coated over with any ſubſtance of this nature, may be excited by friction, and will produce electricity in a metallic plate, in the manner above deſcribed for a very great length of time. Such a plate, together with its metal, has been named the *electrophorus*.

If the diſcharge of an electrified plate be made by the parts of a living animal, a conſiderable pain will be felt chiefly at the extremities of the muſcles. For example, if a man touch the lower metal plate with one hand, and bring the other to the upper plate, at the inſtant of the emiſſion, he will feel a pain at the wriſts and elbows, which as inſtantly vaniſhes. If a larger glaſs plate be

uſed,

uſed, the pain will be felt in the breaſt; if yet larger, the ſenſation will be that of a univerſal blow. This ſenſation has obtained the name of the ſhock; and will deprive animals of life, if ſufficiently ſtrong. The ſhock from a ſquare foot of glaſs in contact with metal, will ſometimes inſtantly kill mice, ſparrows, and the like, but ſometimes only throws them into univerſal convulſions, of which they in general recover. Six ſquare feet of glaſs will deprive a man of ſenſation for a time, if the head be made a part of the circuit through which the electricity moves. No inconvenience has been found from the electric ſhock by men of ſtrong habits, but women of delicate conſtitutions have had convulſions after a violent ſhock. We may obſerve that the electric ſhock is a proof that the electric matter paſſes through the ſubſtance of non-electrics, and not over their ſurfaces alone, as ſome have ſuppoſed.

CHAP. V.

Of Electric Jars; the Velocity of the Shock; Light in the Boylean Vacuum; the charging a Plate of Air, whence is deduced the Action of Pointed Bodies; and of the Electricity which is produced in certain Bodies by heating and cooling.

FOR the ſake of ſimplicity and preciſion, we have related the effects of electrifying glaſs-plates, which however are little uſed. The object of the philoſopher in general is to collect a large quantity of electricity, by means of the ſurfaces of electrics, and it is neither neceſſary nor convenient to uſe flat plates. The electrician therefore accommodates himſelf with a ſufficient number of prepared jars. They are made of various ſhapes and magnitudes, but the moſt uſeful are thin cylindrical glaſs-veſſels, about four inches in diameter, and fourteen in height; theſe are coated within and without, with tinfoil, which is ſtuck on with gum-water, excepting two inches of the

the rim or edge, which is left bare, to prevent the communication between the coatings. About four inches from the bottom, within, is a large cork, through which is inſerted a thick wire, ending in ſeveral ramifications, which touch the inſide coating; the upper end of the wire terminating with a knob, conſiderably above the mouth of the jar. See fig. 139. letter S. When it is required to be charged, it may be held in the hand, or on an uninſulated table, and the knob of the wire applied to the conductor; the inſide coated ſurface becomes poſſeſſed of the electricity of the conductor, and the external ſurface acquires the contrary electricity by means of its uninſulated coating. When a jar of this kind is highly charged, it will diſcharge ſpontaneouſly over the uncoated ſurface, and ſeldom through the glaſs, whereas, when the uncoated ſurface is large, they are more apt to break by that means, and become uſeleſs. Yet, there is no dependance that a jar which has diſcharged itſelf over its ſurface will not at another time break by a diſcharge through the glaſs, as the contrary often happens.

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When a greater degree of electric force is required, larger jars muſt be uſed, in which the form is of no conſequence, farther than convenience requires. But it is leſs expenſive, and quite as effectual, to uſe a number of ſmaller jars, ſo that the quantity of coated ſurface may be the ſame as in the large jars. In this caſe, a communication muſt be formed between all the outſide coatings, which may be done by placing them on a ſtand of metal; and alſo between all the inner coatings, which is beſt done by means of wires. Such a collection is called a battery, and may be charged and diſcharged like a ſingle jar.

In diſcharging electrical jars, the electricity goes in the greateſt quantity through the beſt conductors, and by the ſhorteſt courſe. Thus, if a chain and a wire, communicating with the outer coating, be preſented to the knob of a jar, the greater part of the charge will paſs by the wire, and very little by the chain, which is a worſe conductor, by reaſon of its diſcontinuation at every link. When the diſcharge is made by the chain only, ſparks are ſeen at every link, which is a proof that they are not in contact; and as the chain muſt be

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ſtretched by a conſiderable force before the ſparks ceaſe to appear on the diſcharge, it follows that there is a repulſive power in bodies, by which they are prevented from coming into contact, unleſs by force, as has been obſerved in the former part of this treatiſe.

By accurate experiments it appears, that the force of the electric ſhock is weakened, that is, its effects are diminiſhed, by uſing a conductor of a great length in making the diſcharge. Yet, a very conſiderable ſhock was given by the Abbé Nolet, in the preſence of the French King, to one hundred and eighty men; the firſt of whom formed a communication with the outer coating, the reſt joining hands in a circular line, and the laſt touched the knob of the inner coating. They were all ſhocked at the ſame inſtant. Dr. Watſon, and many other gentlemen of eminence in the philoſophical world, were at the pains of making experiments of the ſame kind, but much more accurate. They found, by means of wire inſulated on baked wood, that the electric ſhock was tranſmitted inſtantaneouſly through the length of 12276 feet.

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When any animal or ſubſtance is to be ſubjected to the ſhock, it is uſually done by means of two chains, one of which connects one extremity of the animal or ſubſtance with the outer coating, and the other being faſtened to, or laid on, the other extremity, is applied to the knob of the inner coating to make the diſcharge. The animal or ſubſtance thus forming a part of the circuit, receives the whole ſhock. The ſtrong ſhock of a battery will melt wire of the ſeventieth of an inch in diameter, and wires of leſs diameters are frequently blown away, and diſperſed. Gunpowder may be fired by a charge of three ſquare feet; the method is, to put it into a quill, and thruſt a wire into each end, ſo as not to meet, and then make theſe wires a part of the circuit. Spirit of wine, ether, and a mixture of common and inflammable air, may alſo be fired by the ſame means, or even by the ſpark from the conductor. Yet, it ſeems probable in theſe caſes, that inflammation does not take place becauſe the electric matter is fire, or in an ignited ſtate, but becauſe the extreme velocity of its motion excites thoſe vibrations in which heat conſiſts, or at leaſt which always accompanies

paries it. A ſtrong ſhock gives polarity to ſmall needles.

Electricity will paſs by means of non-electrics that are ſo ſmall as to be deſtroyed by its paſſage, as has juſt been inſtanced in wires: the force of the exploſion in theſe inſtances is very conſiderable, and is termed the lateral force of electricity. The following is a proof of this, and may be exhibited with leſs than a ſquare foot of coated glaſs, if well charged. At the glaſs-houſe there is generally a great number of ſolid ſticks of glaſs, about a quarter of an inch diameter; if theſe be examined narrowly, ſeveral of them will be found to be tubular for a conſiderable length, but the diameter of the cavity ſeldom exceeds the 200th part of an inch. Select theſe, and break off the tubular part, which may be filled with quickſilver by ſucking; care being taken that no wet previouſly inſinuates itſelf, and then ſend the ſhock through this ſmall thread of quickſilver, which will inſtantly be diſploded, and will break or ſplit the tube in a curious manner.

An experiment ſimilar to this may be made with a glaſs-tube filled with water. Take a

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ſmall glaſs-tube, whoſe cavity is about a quarter of an inch in diameter, fill it with water, and ſtop the end with ſoft pomatum: thro' the pomatum inſert two wires, that they may almoſt touch each other, and make their ends a part of the circuit in the diſcharge of a ſtrong ſhock, from about two feet ſquare of coated glaſs; the conſequence will be, that the water will be diſperſed in every direction, and the tube blown to pieces, particularly in the middle, near the diſcontinuation of the wire: the ends with the wires and pomatum will ſometimes be found undiſturbed. This is a ſtriking inſtance of the velocity and force with which the electric matter is moved.

This property, of being charged and diſcharged, is not peculiar to glaſs, but is common to all other electrics.

If a thin bottle be exhauſted of air by means of the air-pump, it will receive a conſiderable charge by applying its bottom to the electrified prime conductor, during which time the electric matter will paſs thro' the vacuum between the hand and the inner ſurface of that part of the glaſs which is neareſt the prime conductor. This appearance, whoſe cauſe has already been

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in ſome degree explained, is exceedingly beautiful in the dark, eſpecially if the bottle be of a conſiderable length. It exactly reſembles thoſe lights which appear in the northern ſky, and are called ſtreamers, or the aurora borealis. If one hand be applied to the part of the bottle which was applied to the conductor, while the other remains at the neck, the ſhock will be felt, at which inſtant the natural ſtate of the inner ſurface is reſtored by a flaſh, which is ſeen pervading the vacuum between the two hands.

The electric ſhock may be given from a plate of air, by means of two large plates of metal, or rather boards covered with tinfoil; one of which is to be ſuſpended to the prime conductor, and the other placed parallel to it on an uninſulated ſtand, at a convenient diſtance. Theſe boards may be regarded as the coatings of the plate of air contained between them, and if a communication be formed between them, by touching the uninſulated board with one hand, and applying the other hand to the conductor, the ſhock will be felt accordingly. It is almoſt unneceſſary to obſerve, that if the electricity be powerful, or the diſtance between

tween the plates ſmall, the charge will paſs from the one to the other in a ſpark through the air.

If we compare this experiment with what has already been obſerved reſpecting the charging and diſcharging electric bodies, it will appear that moſt of the electric phenomena are the conſequences of the air being charged. Thus, the prime conductor imparts its electricity to the ſurface of air immediately contiguous, and when the ſpark is drawn the diſcharge is made to the non-electrics, namely, the floor and wainſcot of the room, which are in contact with the oppoſite ſurface. The charge of electrics has already been obſerved to be greater, the nearer the ſurfaces are to each other; thus, glaſs beyond half an inch thickneſs cannot be charged by our machines: in like manner, the diſcharge, that is to ſay, the ſpark from the conductor, will be greater, when a large company ſtand about it than at other times, the body of air which is interpoſed between the conductor and the neareſt uninſulated non-electrics being then leſs in thickneſs than at other times. It follows alſo, that a large conductor will give a larger ſpark than a leſs; the diſcharge being from a ſurface proportionally

tionally greater. And ſince this diſcharge conſiſts chiefly of the electric matter, reſiding at, or near the ſurface of contact, and little, if at all, of that which may be within the ſubſtance of the conductor, it is of no conſequence whether the conductor be a ſolid non-electric or hollow, provided the ſurface be unaltered in form and magnitude. Hollow cylinders of copper, or tin, or wood, covered with tinfoil, or ſtrongly gilt, are the conductors generally in uſe; and in the other circumſtances we have here related by inference, experience agrees with our concluſions.

It is a conſequence of the air being charged that broad non-electric ſurfaces draw large ſparks from the conductor; for the ſparks are the diſcharges of a large plate of interpoſed air. A leſs ſurface will draw a leſs ſpark, but becauſe the ſame machine charges leſs ſurfaces higher than greater, the ſpontaneous diſcharge through the body of the electric air will be made at a greater diſtance of the ſurfaces, that is to ſay, the ſparks will be longer. If the ſurface of the non-electric preſented be yet leſs, the ſparks, by the ſame reaſon, will be leſs, and emitted to a ſtill greater diſtance.

And if the ſurface be indefinitely ſmall, or, in other words, if the non-electric be pointed, the ſpark may be ſo ſmall as to be inviſible, and the diſtance to which it can be emitted may be unlimited. The effect of pointed bodies ſeems to depend on circumſtances of this nature; but the reaſon of the different appearances of the light on points electrified, poſitively or negatively, ſtill remains a difficulty. It would not, indeed, be difficult to frame an hypotheſis for the purpoſe of removing it, but it is ſafer to wait till the buſineſs is accompliſhed by obſervation and experiment.

Since attraction and repulſion are circumſtances which, in almoſt every ſituation, attend bodies in an electric ſtate, philoſophers avail themſelves of theſe phenomena to diſcover the ſtate and degree of electricity. The electrometer rp, in fig. 139. indicates the ſtate of the conductor by the diſtance to which it elicits the ſpark; but it has the inconvenience of carrying off the electricity at the inſtant in which it becomes uſeful, and is, beſides, totally improper for denoting ſmall degrees of intenſity. Its chief application is to give a

number

number of ſhocks of preciſely the ſame force. Small degrees of electricity are very well ſhewn by the divergence of two fine hempen-threads, ſuſpended together from the conductor. If little balls of pith or cork be faſtened to the ends of the threads, they will ſerve to denote ſtill greater intenſities, as they will not ſo ſoon arrive at their utmoſt divergence by the mutual repulſion. Fig. 140. is a very uſeful electrometer upon this principle. It conſiſts of an upright ſtick of box-wood, a b, on one ſide of which is affixed a graduated ſemi-circle; d is a ball of pith or cork, and is ſtuck upon the end of a ſmall rod or radius of wood, which, by means of a ſmall axis at c, is moveable in a plane parallel to that of the ſemi-circle. This electrometer is fixed upright on the prime conductor; the radius muſt therefore hang perpendicularly down when it is not electrified; and according to the intenſity of the electric ſtate given to the conductor, the repulſion muſt cauſe the ball to aſcend. The aſcent will be marked by the graduations.

This laſt electrometer, though by far the moſt uſeful of any, is conſiderably imperfect.

It is much more ſenſible of ſmall variations in the electric force when at the beginning of the graduations than any where elſe, and is not reducible to a ſtandard, that is to ſay, two electrometers will not agree, though equally electrified. This laſt imperfection is common to every inſtrument which has yet been invented for the purpoſe of meaſuring the intenſity of electricity.

Theſe methods ſerve to eſtimate the force of the electric repulſion, but do not indicate whether the electricity be poſitive or negative. If the electricity be ſtrong, the nature of its ſtate may be known by preſenting an uninſulated metallic point, which will be illuminated or tipped, with a light correſponding with the contrary electricity to that of the conductor. (See p. 378.) To diſcover the nature of ſmaller degrees of electricity, a downy feather may be inſulated by ſuſpending it by a ſlender ſilk-thread, and then rendered electric, by bringing it in contact with the cylinder or conductor of the machine. The feather in this ſtate will be repelled by bodies which poſſeſs the ſame kind of electricity as itſelf, and will be attracted by all other bodies.

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We ſhall finiſh our general account of artificial electricity with pointing out ſome of the other means by which it may be acquired; but which the theory we at preſent poſſeſs is too imperfect to explain.

Sulphur melted in an earthen veſſel, and placed to cool upon uninſulated conductors, is ſtrongly electric when taken out, but is not ſo when it has ſtood to cool upon electric ſubſtances.

Sulphur melted in a glaſs-veſſel acquires a ſtrong electricity in the circumſtances above-mentioned, whether the veſſel be placed on electrics or not; but ſtronger in the former caſe. This electricity is yet ſtronger, if the glaſs be coated with metal. In theſe caſes the glaſs is always poſitive, and the ſulphur negative. It is particularly remarkable, that the ſulphur acquires no electricity till it begins to cool and contract, and is the ſtrongeſt at the time of the greateſt contraction; whereas the electricity of the glaſs is at that time weakeſt, and is the ſtrongeſt of all when the ſulphur is ſhaken out before it begins to contract, or has acquired any negative electricity.

It has been obſerved, that ſilk or worſted ſtockings become electrical after being worn ſome hours, more particularly the ſilk, as does alſo a beaver-ſhirt worn between two others. If a white and a black ſilk-ſtocking be worn on the ſame leg, they obtain contrary electricities. *When drawn off together they* ſhew very little *ſigns of electricity, but, upon* ſeparating them, each indicates an electrical ſtate ſo ſtrongly, that the repulſion inflates them, ſo as to exhibit the intire ſhape of the leg. If the two ſtockings be allowed to come together, they ſtrongly attract each other, the inflation ſubſides, and they ſtick very cloſely together; in which ſituation they retain their electric ſtate, notwithſtanding the approach of the ſharpeſt metallic point. A ſecond ſeparation again exhibits their reſpective electricities as before; and this may be done ſeveral times without much diminiſhing their electricities. The electricity of the black ſtocking is negative, and of the white poſitive.

The tourmalin is a hard pellucid gem, of a red colour, and is brought from the iſland of Ceylon by the Dutch. It poſſeſſes the property of aſſuming an electric ſtate if heated;

one

one ſide of it becoming poſitive, and the other negative. If this electric ſtate be taken off by contact, the ſtone will become electric as it cools; but with this difference, that the ſide, which during the heating was poſitive, will now be negative, and the other ſide poſitive, which before was negative. But if the electric ſtate be not taken off, the ſame kind of electricity will be found on the ſame ſide during the whole time of heating and cooling. Either ſide of the tourmalin will become poſitive by friction, and both may be made ſo at the ſame time.

Theſe are the chief properties of this very remarkable ſtone, which are alſo common to the Brazil topaz, and ſome other gems. There are ſeveral important particulars relative to this and every other branch of electrical knowledge, which cannot be enumerated and deſcribed, in an introductory book, on account of the great length of detail they would require. For theſe, the ſtudent muſt have recourſe to treatiſes written expreſsly on this ſubject. There are alſo a number of fanciful and pleaſing variations of the common experiments. Bells are rung by an inſulated clapper, which is

alternately attracted and repelled between two bells in oppoſite ſtates of electricity; figures of men and women cut in paper are made to dance by the attraction and repulſion between two metallic plates; light mills of paſteboard are driven round by the current of air from electrified points, &c. &c. particular accounts of all which may be had in pamphlets, which are frequently ſold by the makers of the electrical apparatus.

CHAP.

CHAP. VI.

Of Natural Electricity; and of the Identity of Lightning and the Electric Matter.

THAT electricity is no trivial or confined ſubject, muſt appear from what has already been ſaid, ſince there is no body in nature that is not acted upon by it, either as a conductor or non-conductor. The importance of the electric matter in the mundane ſyſtem is more particularly confirmed by obſervations on thoſe phenomena which take place without the concurrent operation of man. Of theſe it will be proper to give ſome account.

Several fiſhes poſſeſs the property of giving the electric ſhock. The torpedo, or numbing fiſh, and one or more ſpecies of eels, from Surinam, if touched by the hand, a metal rod, or any other conductor, give a conſiderable ſhock to the arm, but may be ſafely touched by means of a ſtick of ſealing-wax. The ſhock depends on the will of the fiſh, and is tranſmitted to a great diſtance, ſo that if perſons

ſons in a ſhip happen to dip their fingers or feet in the ſea, when the fiſh is ſwimming at the diſtance of fifteen feet, they are affected by it.

But the moſt remarkable appearances of electricity, which are viewed with ſurpriſe and admiration by all ranks of people, are thoſe which may be termed atmoſpherical, as for the moſt part exiſting in, or depending on the ſtate of the atmoſphere. Lightning is proved to be an electric phænomenon, and there is little doubt but the aurora-borealis, whirlwinds, water-ſpouts, and earthquakes, depend on the ſame principle.

The reſemblance between the electric ſpark and lightning, is ſo obvious, that we find it among the earlieſt obſervations on the ſubject; but the proof of the important theorem of their identity was reſerved for Dr. Franklin, who is ſo juſtly celebrated for his many diſcoveries in this branch of phyſics. He firſt obſerved the power of uninſulated points, in drawing off the electricity from bodies at great diſtances, and thence inferred that a pointed metallic bar, if inſulated at a conſiderable height in the air, would become electrical by communication from the clouds dur-

ing

ing a thunder-ſtorm. He gave this thought to the public; and ſeveral machines, conſiſting of inſulated iron bars, erected perpendicular to the horizon, and pointed at top, were ſet up in different parts of France and England. The firſt apparatus that was favored with a viſit from this ethereal matter, was that of Monſ. Dalibard, at Marly la Ville, about ſix leagues from Paris. It conſiſted of a bar of the length of forty feet, and was electrified on the tenth of May, 1752, for the ſpace of half an hour, during which time the longeſt ſparks it emitted meaſured about two inches.

Dr. Franklin, after having publiſhed the method of verifying his hypotheſis concerning the ſameneſs of electricity with the matter of lightning, was waiting for the erection of a ſpire in Philadelphia to carry his views into execution; not imagining that a pointed rod of a moderate height could anſwer the purpoſe; when it occurred to him, that by means of a common kite he could have a readier and better acceſs to the regions of thunder, than by any ſpire whatever. Preparing therefore a large ſilk handkerchief, and two croſs ſticks

of

of a proper length, on which to extend it; he took the opportunity of the firſt approaching thunder-ſtorm, to walk into a field in which there was a ſhed convenient for his purpoſe. But, dreading the ridicule which too commonly attends unſucceſsful attempts in ſcience, he communicated his intended experiment to nobody but his ſon, who aſſiſted him in raiſing the kite.

The kite being raiſed, the end of the ſtring being tied to a ſilk ſtring which he held in his hand, and a ſmall key being faſtened at the place of junction, a conſiderable time elapſed before there was any appearance of its being electrified. One very promiſing cloud had paſſed over it without any effect; when, at length, juſt as he was beginning to deſpair of his contrivance, he obſerved ſome looſe threads of the hempen ſtring to ſtand erect, and to avoid one another juſt as if they had been ſuſpended on a common conductor. Struck with this promiſing appearance, he immediately preſented his knuckle to the key, and, let the reader judge of the exquiſite pleaſure he felt at that moment, the diſcovery was complete. He perceived a very evident

electric

electric ſpark. Others ſucceeded, even before the ſtring was wet, ſo as to put the matter paſt all diſpute, and when the rain had wetted the ſtring, he collected the electricity very copiouſly. This happened in June 1752, a month after the electricians in France had verified the ſame theory, but *before he had* heard of any thing they had done.

The grand practical uſe which the Doctor made of this diſcovery, was to ſecure buildings from being damaged by lightning, a thing of vaſt conſequence in all parts of the world, but more eſpecially in ſeveral parts of North America, where thunder-ſtorms are more frequent, and their effects, in that dry air, more dreadful, than they are ever known to be with us.

This great end is accompliſhed by ſo eaſy a method, and by ſo cheap and ſeemingly trifling apparatus, as fixing a pointed metalline rod higher than any part of the building, and communicating with the ground or rather the neareſt water. This wire the lightning is ſure to ſeize upon, preferably to any other part of the building, unleſs it be very large and extended, in which caſe wires may be erected

erected at each extremity; by which means this dangerous power is ſafely conducted to the earth, and diſſipated without doing any harm to the building.

Conducting rods are now become very common, both for the purpoſe of ſecuring buildings, and of making obſervations on the ſtate of the atmoſphere. *The beſt of thoſe* which are intended for the latter purpoſe, is the following. On the top of any building, which will be the more convenient if it ſtand upon an eminence, erect a pole as tall as a man can manage without difficulty, having on the top of it a ſolid piece of glaſs or baked wood, a foot in length. Let this be covered with a tin or copper veſſel in the form of a funnel, to prevent its ever being wetted. Above this let there riſe a long ſlender rod, terminating in a pointed wire, and having a ſmall wire twiſted round its whole length, to conduct the electricity the better to the funnel. From the funnel, let a wire deſcend along the building about a foot diſtance from it, and be conducted through an open ſaſh into any room which ſhall be moſt convenient for managing the experiments. In this room

let

let a proper conductor be insulated and connected with the wire coming in at the window. This wire and conductor, being completely insulated, will be electrified whenever there is a considerable quantity of electricity in the air; and notice will be given when it is properly charged, either by the mutual repulsion of two small balls of cork hung to it by threads, or by the ringing of two small bells, the one suspended from, and communicating with the conductor, and the other uninsulated: these bells will be in opposite states of electricity when the conductor is electrified, and if a clapper or small metallic ball be hung by a silk thread between them, it will be alternately attracted and repelled by each, and consequently indicate the electricity of the conductor by ringing.

To make these experiments in perfect safety, the electrified wire should be brought within a few inches of a conducting rod, which serves to guard the house, that the redundant electricity may pass off that way, without striking any person who may happen to stand near it. The conductor to guard the house should consist of a rod, without breaks or discontinuities,

continuities, between one fourth and one half of an inch thick, if it be of iron, but ſmaller if it be braſs or copper, terminating upwards in a ſharp point about four or five feet above the higheſt part of the building: it is convenient that this point be gilt, to preſerve it from ruſting. The lower end of the rod ſhould, if poſſible, be continued to ſome well or running water, or otherwiſe it ſhould be ſunk ſeveral feet into the ground, at the diſtance of ſome yards from the building. It is of no conſequence how many bendings are made in the rod, but it is much better to faſten it to the outſide than the inſide of the building; for theſe conductors are known to emit ſparks during thunder-ſtorms, notwithſtanding their inſertion in the earth, from which fatal conſequences may be apprehended when the electric force is very great.

It is clear, from many inſtances, that the lights which are ſeen at the maſt-heads of ſhips, and on the vanes of ſome churches during thunder, owe their origin to the electric matter paſſing by means of uninſulated points.

The polarity of the compaſs-needles has been known, in ſeveral inſtances, to be de-

ſtroyed

ſtroyed, or reverſed by lightning. An effect which, as has been obſerved, may be produced *in parvo* by the electric ſhock from glaſs.

If the electrician be deſirous of making experiments upon the electricity of the atmoſphere to greater exactneſs, he muſt raiſe a kite, by means of a ſtring in which a ſmall wire is twiſted. The lower extremity of this line muſt be ſilk, and the wire muſt terminate in ſome metallic conductor of ſuch a form as ſhall be thought moſt convenient. But it is dangerous to raiſe it upon the approach of a thunder-ſtorm; and upon this occaſion the common apparatus for drawing electricity from the clouds will probably anſwer every intended purpoſe.

CHAP. VII.

Of Lightning, and other Meteors.

TO know that lightning and the electric matter are the ſame, is a very capital advance in natural philoſophy, but we muſt ſtill remain ignorant of the cauſes of many of the appearances which accompany lightning, ſo long as our acquaintance with the properties of electricity is ſo very imperfect. We know that the clouds are almoſt always electrified, ſometimes poſitively, and ſometimes negatively; but whence, or by what means they acquire that ſtate; whether by the heating or cooling of the air, upon the Tourmalin principle, whatever that may be, or whether the clouds be only the conductors by which the electric matter is conveyed through the air, from places in the earth where it is redundant to other places where there is a deficiency, cannot eaſily be determined. The firſt is the conjecture of the well known Mr. Canton, and the latter is the chief propoſition in the theory of that great philoſopher Sig. Beccaria of Turin.

It

It is probable that both circumſtances may conduce to the effect; the heating or cooling of the air may produce, or rather collect, that electricity which is ſo great an agent in atmoſpherical events, and its diſcharge may be effected in the manner in which Signior Beccaria has, with great probability, ſuppoſed it to be accompliſhed.

A thunder-ſtorm uſually happens in calm weather. A dark cloud is obſerved to attract others to it, by which it continually increaſes in magnitude and apparent denſity. When the cloud is thus grown to a great ſize, its lower ſurface ſwells in particular parts towards the earth, ſometimes by light flimſy clouds, and ſometimes by an inferior protuberance. During the time that the cloud is thus forming, flaſhes of lightning are ſeen to dart from one part of it to the other, and often to illuminate the whole maſs; and ſmall clouds are obſerved moving rapidly, and in very uncertain directions beneath it. When the cloud has acquired a ſufficient extent, the lightning ſtrikes the earth in two oppoſite places; the path of the lightning lying through the whole body of the cloud and its branches.

That thunder-clouds do nothing more than conduct the electric matter from one place to another, is not only probable, on account of its ſtriking in two places, but likewiſe from the conſideration, that the emiſſion of the flaſh would deſtroy the electric ſtate of the clouds, if it were not immediately recruited from ſome other part. But the electric ſtate is not deſtroyed after a flaſh, if we may judge either from the electric apparatus, or from the cloud itſelf; for the firſt appears to be not leſs electrified, and the latter is the next moment ready to make as great a diſcharge as before. Beſides, If the two flaſhes of lightning, which ſtrike at different places, nearly at the ſame time, were ſimple, ſimilar and independent diſcharges of the cloud, why ſhould they reſemble each other? and yet they do very much, as appears by obſerving a thunder-ſtorm at a diſtance. Then it is ſeen, that if one part of the cloud give a ſingle flaſh, the other extremity will give, or rather receive, a ſingle flaſh a ſhort time or the inſtant after; but if it give two, three, or four quick ſucceſſive flaſhes, the other extremity will receive a like number a little, but very perceptible time after. The angular diſ-

tance

tance between the places of theſe correſpondent flaſhes is frequently four or five points of the compaſs.

It is remarkable, that moſt detached clouds, whoſe angular heights are but ſmall, and which conſequently may be viewed in profile, are variouſly arched at their upper ſurface, while their under ſurface is horizontal. This appearance is particularly obſervable in thunder-clouds, and alſo takes place in the ſmoke of reſin, or ſteam of water, electrified by the common machine.

Whatever may be the cauſe that diſturbs the equilibrium of the electric matter in the atmoſphere, it may eaſily be conceived, that when ſuch diſturbance happens in the upper, and highly rarefied regions of the air, the equilibrium will be reſtored by dartings and electric coruſcations through the vacuum, ſimilar to thoſe exhibited in the vacuum of the air-pump. This conſideration accounts for the aurora borealis, which has commonly a motion of darting or undulating between two oppoſite parts of the heavens.

In clear and calm weather, when the electricity is not very ſtrong, it may paſs through

the air without bringing any great quantity of vapours into its courſe, and, according to the conductors it meets in the air, it will ſometimes be rendered viſible for ſmall parts of its paſſage, and occaſion thoſe appearances which we call ſhooting-ſtars. It is obſervable, that ſhooting-ſtars are uſually very low in the air, and that in general they all direct their courſe the ſame way.

The ignis fatuus, or Will-with-the-wiſp, is a luminous meteor that ſeldom appears more than ſix feet above the ground. It is found chiefly about bogs, and is always in motion, varying both its figure and ſituation in a very uncertain manner. In the plains in the territory of Bologna, they are frequently very large, and give a light equal to a torch; and there are ſome places where one may be almoſt ſure of ſeeing them every dark night. The moſt probable conjecture concerning theſe meteors is, that they conſiſt of inflammable air which has been kindled by electricity.

Speaking of water-ſpouts, we obſerved that the convergence of winds and their conſequent whirling motion, was a principal cauſe in producing that effect; but there are

appear-

appearances which can hardly be ſolved by ſuppoſing that to be the only cauſe. They often vaniſh, and preſently appear again in the ſame place: whitiſh or yellowiſh flames have ſometimes been ſeen moving with prodigious ſwiftneſs about them, and whirlwinds are obſerved to electrify the apparatus very ſtrongly. The time of their appearance is generally thoſe months which are peculiarly ſubject to thunder-ſtorms, and they are commonly preceded, accompanied or followed by lightning, the previous ſtate of the air being ſimilar. And the long eſtabliſhed cuſtom, which the ſailors have, of preſenting ſharp ſwords to diſperſe them, is no inconſiderable circumſtance in favor of the ſuppoſition of their being electrical phenomena. Perhaps the aſcending motion of the air, by which the whirling is produced, may be the current which is known to iſſue from electrified points, as the form of the protuberance in the ſea is ſomewhat pointed; and the electrified drop of water, heretofore mentioned, may afford conſiderable light in explaining this appearance.

It is extremely probable that earthquakes owe their original to the diſcharge between

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